MINISTRY OF WATER AND IRRIGATION

Water Resource Policy Support

TECHNICAL REPORT: IRRIGATION ADVISORY SERVICES PROGRAM IN THE HIGHLANDS AREA

By

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MWI/ARD WATER RESOURCES POLICY SUPPORT

SHORT-TERM CONSULTANT SUMMARY REPORT

NAME: Blaine R. Hanson, Irrigation and Drainage Specialist, University of California, Davis
SUBJECT: Development of Irrigation Advisory Service Program
PROGRAM: Groundwater Management
SUPERVISOR: Mohammed Chebaane
ARRIVAL TIME AND DATE: 7:30 pm, August 11, 2000
DEPARTURE TIME AND DATE: 7:10 am, September 2, 2000

OBJECTIVES: To make an assessment of the potential of an Irrigation Advisory Service program in the NE Highlands of the AZB to assist farmers in increasing profitability and improving irrigation water efficiency.

SUMMARY OF ACTIVITIES:

1. Reviewed procedure and materials being used to estimate crop evapotranspiration
2. Conducted field evaluations of irrigation systems for four days in the Highlands area.
3. Visited the Irrigation Advisory Service project in the Jordan Valley
4. Visited with officials of the Ministry of Water and Irrigation.
5. Presented seminar to interested parties of ARD and MWI.

SUMMARY OF RESULTS:

1. Prepared report on the results of the irrigation system evaluations.
2. Prepared a series of articles on irrigation water management that might be used for an irrigation educational program.
3. Prepared a report on developing an irrigation advisory service for the Highlands area.
4. Prepared a proposed training program for irrigation advisors.

SUMMARY OF RECOMMENDATIONS:

1. Minibasin irrigation of tree crops has the potential for good irrigation efficiency and should be encouraged.
2. Drip emitters should not be used with minibasins because of their potential for clogging.
3. The possibility for manufacturing emitters with fixed discharge rates ranging between 50 to 80 l/h should be investigated.
4. Better field wide irrigation system design to encourage pressure regulation is recommended for both minibasins and drip irrigation systems.
5. Basal crop coefficients should be used for the row crops because the use of plastic mulch probably eliminates most of the soil evaporation.
6. Crop coefficients for row crops should be adjusted for the bed spacings used in the Highlands area.
7. FAO56 single crop coefficients should be used for the tree crops.
8. A pilot IAS programs is recommended to assist Highlands farmer to improve their irrigation practices. A minimum of three years is needed to fully assess the response of tree crops to changes in irrigation water management. Several years also will be needed for row crops to determine their response to changes in irrigation water management.

FUTURE PROGRAM: A visit may occur in the spring of 2001 to help initiate some of the field demonstration activities.

SIGNED (CONSULTANT) DATE:

SIGNED (SUPERVISORS)

EXECUTIVE SUMMARY

Groundwater is the only source of irrigation water in the Highlands area of Jordan. However, excessive pumping in the area has caused a severe groundwater overdraft. During the past few years, the overdraft problems have been aggravated by a continuing drought.

The limited water supplies in the Highlands area means that farmers must irrigate as efficiently as possible. Efficient irrigation involves good irrigation system design, maintenance, and management. The system design and maintenance affects the uniformity of the irrigation water applied throughout a field. The emissions uniformity, an index used to describe the uniformity of applied water, is also an estimate of the irrigation efficiency of a properly managed irrigation district. The higher the emissions uniformity, the higher the potential maximum irrigation efficiency.

Managing an irrigation system involves knowing how much water to apply and knowing how much water is being applied. Knowing how much to apply requires information on crop evapotranspiration, while knowing how much is being applied during an irrigation requires good flow meter measurements.

It has been my experience that no matter how much information is available, an educational program is necessary to teach farmers how to better manage their irrigation water. Simply providing handouts and other written material to them is insufficient.

Thus, the objectives of my visit to Jordan and the Highlands area are:

• Briefly review the procedures for estimate crop water requirements in the Highlands area.

- Conduct field evaluations of farms in the Highlands area to determine the need for an Irrigation Advisory Services (IAS) Program.
- Develop educational material that might be used for an IAS program.
- Develop a practical plan for the establishment and implementation of a pilot IAS program.
- Develop a plan for initiating a private IAS program.

Review of Crop Water Requirements

The method being used to estimate crop water requirements in the Highlands area is to determine a reference crop evapotranspiration using climatic data and the Penman-Monteith (PM) equation. The reference crop evapotranspiration is multiplied by a crop coefficient to obtain the crop water use. The crop coefficient depends on crop type, stage of growth, and cultural practices.

The approach being used by MWI/ARD is the recommended method in FAO56 and other publications on evapotranspiration. The PM equation has been found to be highly accurate in estimating reference crop evapotranspiration.

FAO56 also contains crop coefficients and crop calendars for many crops. Unless local crop coefficients are available, it is recommended that the FAO56 values be used. However, for row crops in the Highlands area, I recommend that the basal crop coefficients be used. These coefficients are used for conditions where water evaporation from the soil is minimal. Because plastic mulch is used for the drip irrigated row crops in the Highlands area, it is my opinion that evaporation is minimal, and thus, the basal crop coefficients are appropriate for that area.

I recommend that the single crop coefficients be used for the tree crops. Tree crops are irrigated using a minibasin irrigation method, which consists of forming basins, 2 to 3 m in diameter, around trees. Thus, some evaporation occurs from these basins, but the actual amount is unknown. However, the FA056 single crop coefficients for olive are very similar to those used in the San Joaquin Valley in California for olive trees irrigated with microsprinklers.

Field Evaluations

The objectives of the field evaluations are to determine the uniformity of irrigation systems in the Highlands area and to identify factors contributing to their performance. Observations also were made on any fertigation and chemigation (clogging prevention) practices. Eleven fields were used for this study covering a range of crop and qualitative estimates of irrigation efficiency made by a previous survey conducted by MWI/ARD personnel. Table 1 shows the characteristics of these sites.

Table 1. Characteristics of the evaluation sites.

No.	Site ID	Crop	Irrigation Method	Tree Spacing (m)	Row Spacing (m)	Emitter Spacing (m)	Lateral Length (m)
1	MF1129Q	Peach	M1[1]	4	4	4	70
2	MF1129Q	Grape	D[2]	3	4	0.4	50
3	MF3416Q	Apple	M1[1]	2	*	2	40
4	Al-1093	Olive	M1[1]	6	7	6	60-66
5	Al-1097	Olive	M1[1]	6	7	6	50
6	Al-3062	Apple	M1[1]	4	4	4	28
7	Al-3062	Squash	D[2]	*	2	0.4	50
8	Al-3062	Tomato	D[2]	*	2	0.4	50
9	Al-3080	Tomato	D[2]	*	2	0.4	50
10	Al-3082	Tomato	D[2]	*	2	0.4	50
11	Al-1088	Olive	M2[3]	8	8	8	64

[1] M1 = minibasin using adjustable emitter
[2] D = drip irrigation
[3] M2 = minibasins using drip emitters

The evaluations revealed that there are two types of irrigation methods used by the Highlands farmers. Trees are irrigated using minibasins, which are small basins, about 2 to 3 m in diameter. One basin is used per tree. Polyethylene tubing containing one adjustable emitter per basin supplies water to the minibasins. Emitter discharge rates range from 50 to 80 liters per hour. For row crops, drip irrigation is used. Drip tubing with an emitter spacing of 0.4 m is installed beneath plastic mulch. The length of the drip lines is about 50 m.

Table 2 shows the results of the evaluations. The emissions uniformity (EU), defined as the ratio of the average discharge rate of the lowest one-fourth of the measured discharge rates to the average of all measured rates, was used as the index of uniformity. As can be seen, minibasin EU ranged 57 to 83 percent. Most of the variability in the emitter discharge rates is believed to be variation in the adjustments of the emitters. There appears to be little clogging of these devices. However, at one site, drip emitters were used in the minibasins instead of adjustable emitters. Because of clogging of these emitters, a relatively low EU was found.

The uniformity along the drip irrigation laterals was very good. However, the data at Site 7 revealed a design problem in these irrigation systems. The average emitter discharge rate of the lateral near the field inlet was more that twice that of a lateral at the other end. This difference was caused by excessive pressure losses throughout the field due to friction losses in the submain pipeline and elevation changes.

Table 2. Results of the evaluations.

No.	Site ID	Crop	Irrigation Method	Average Emitter Discharge Rate (l/h)	E.U (%)
1	MF1129Q	Peach	M1	79.4	57[3]
2	MF1129Q	Grape	D	5.1	26[3]
3	MF3416Q	Apple	M1	56.7	76[2]
4	Al-1093	Olive	M1	69.5	62[3]
5	Al-1097	Olive	M1	67.0	83[3]
6	Al-3062	Apple	M1	72.6	72[3]
7	Al-3062	Squash	D	1.6	61[4]
8	Al-3062	Tomato	D	2.3	89[5]
9	Al-3080	Tomato	D	2.9	90[5]
10	Al-3082	Tomato	D	2.8	86[5]
11	Al-1088	Olive	M2	51.5	59[5]

[1] Adjustable nozzles used in minibasins
[2] Drip Emitters used in minibasins
[3] Blockwide EU
[4] Fieldwide EU; Lateral EU's were 84 and 88 percent for inlet and end laterals, respectively.
[5] Lateral EU

Based on these evaluations, the following are recommended:

• The minibasin irrigation method used for tree crops has the potential for good irrigation efficiencies provided the emitters are carefully adjusted. Thus, methods need to be developed to help growers learn how to make these adjustments. Drip emitters should be avoided for this irrigation method.

• The possibility of developing emitters with fixed flow rates should be investigated.

• The field wide design of irrigation system should be modified to reduce the effect of pressure changes throughout a field. Fields should be split into blocks using manifolds connected to the lateral. At the inlet of each manifold, pressure regulators should be installed to regulate the pressure throughout the field.

Educational Materials

Irrigation water management is a complex process involving areas such as soil-plant-water interactions, water quality, irrigation system design and maintenance, and crop evapotranspiration. Yet, my experience has been that many if not most farmers have had little education in the many aspects of water management. The four days of evaluations in the Highland area indicates that these farmers need some type of educational programs, as do farmers elsewhere. These programs are particularly needed in areas experiencing limited water supplies, poor water quality, and/or where adverse environmental impacts occur as a result of irrigation. A suggested educational program is:

- Use short presentations such a slide shows, etc. to present information in a general manner.
- Conduct workshops to provide in-depth instruction and to give hands-on experience.
- Conduct field demonstrations to show how to install equipment, measure flow rates, show research results, check for emitter clogging, etc.
- Develop educational material on the various topics of irrigation water management. The material might consist of manuals, one-page handouts, and leaflets.

One component of an educational program is developing and publishing material on irrigation water management for farmers. Such material might include manuals, handouts, leaflets, etc.

As part of my program with the University of California, Davis, seven manuals on irrigation water management have been developed. Each manual consists of a series of short chapters, each on some aspect of irrigation. Most chapters have been designed to be used as handout materials. I have modified some of the chapters and provided them to MWI/ARD for use in a pilot Irrigation Advisory Service program. These materials are contained in Appendix B.

Developing an Irrigation Advisory Service Pilot Program

Need for a Pilot Program

The evaluations and surveys conducted by MWI/ARD have clearly shown problems to exist in the management of irrigation water by farmers. Data on groundwater pumping suggest that in many cases, considerable overirrigation is occurring, while in some cases, deficit irrigation exists. Field evaluations have shown that farmers have little knowledge about the performance characteristics of their irrigation systems, and because of this lack of knowledge, some areas of field received much more irrigation water than do other areas. Thus, educating farmers about the aspects of irrigation water management is needed to improve irrigation efficiency in the Highlands areas.

Objective of the IAS Pilot Program

The objective of the IAS pilot program is to establish a program to help a small number of farmers in the Highland area improve their water management practices, and based on these results, evaluated the potential for expanding the program to reach a relatively large number of clientele.

Activities of the Pilot Program

This program should focus on a few farmers who would be willing to allow some changes to be made in their irrigation water management practices. Both educational and demonstration activities should be part of this program. A list of possible activities is as follows.

Educational activities.

• Develop leaflets, handout material, and manuals of irrigation water management. These materials should be designed to help educate farmers on irrigation water management. Avoid educational material that is very general.

• Conduct workshops and field demonstrations to show techniques and methods of improved irrigation water management.

• Develop a mailing list of all farmers in the Highland area for distribution of educational information, announce of meetings, etc. (Note: this activity has been completed.)

• Coordinate with those farmers willing to participate in a pilot program in developing farm-level demonstrations and applied demonstration projects.

Demonstration Activities

• Conduct field demonstrations to determine relationships between applied water and crop yield/quality. These studies should consist of applying irrigation water in amounts ranging from deficit irrigation to overirrigation to develop crop production functions for the crops grown in the Highlands area. Several years will be required to develop these relationships for tree crops.

• Demonstrate using soil moisture sensors to schedule irrigations. Criteria should include the instrument reading at which irrigation should occur and placement of the instrument relative to the water source, i.e. drip tape, minibasins.

• Investigate the economics of deficit irrigation versus adequate irrigation. This activity is suggested because some farmers are deficit irrigating their entire farm due to limited water supplies. Are they economically better off deficit irrigating the entire farm or reducing the irrigated area to that which can be adequately irrigated?

- Promote regulated deficit irrigation of trees and vines to determine the potential of this management approach for saving water. Regulated deficit irrigation has been investigated in Spain and the US as a management tool for water conservation. It involves deliberately under-irrigating trees at certain stages of growth. Research thus far has indicated that some tree crops can be stressed at certain stages of growth without adversely affecting yield. For example, during some growth stages of olive, water applications might be reduced by 50 percent without any yield loss. However, because of the nature of tree crops, it may take several years before any results become evident.
- Develop crop coefficients for row crops that are appropriate for those cultural practices used in the Highland area.
- Investigate new materials for irrigation. For example, an adjustable nozzle is used for minibasins irrigation. It may be possible to develop emitters with fixed discharge rates that will satisfy the irrigation requirements yet maintain a high level of field wide uniformity?

<u>Procedure for Developing a Pilot Program</u>

- Identify farmers who would be willing to participate in a pilot program. Based on the evaluations and surveys, farmers should be identified who might be willing to participate in a pilot program. (Note: this activity has been completed by MWI/ARD.)
- Visit the farmers and explain the objectives and activities of the program. (Note: this activity has been completed by MWI/ARD.)
- Hire personnel who are qualified and who can be adequately trained to be irrigation advisors. It is recommended as a minimum, irrigation advisors should have a bachelor's degree in civil/agricultural engineering, agronomy, plant science or some related field.

- Train the irrigation advisors in the principles of irrigation water management and in conducting farm level studies.
- Develop contacts with the private sector that might be interested in being involved in the IAS pilot program and in continuing the IAS program after the pilot project is completed (this activity has started).
- Determine and purchase the equipment and support needed to conduct both educational and applied research activities.
- Start the program by contacting the interested farmers and start installing instruments and conducting experiments.
- Conduct educational activities to disseminate the results of the program to all interested farmers.
- Expand the program as needed.

Developing a Private IAS Program

The long-term goal of the Irrigation Advisory Services Program is to eventually privatize the advisor program with farmers paying 100 percent of the program costs. The primary consideration for transforming the IAS program into a private program is, can an advisor generate sufficient income for salary and operating expenses.

Some options for developing a private IAS program are as follows:

- The advisor charges a fee only to those farmers who utilize his services. The fee could be based on number of dunums or on a per-site instrumented. An irrigation equipment company has expressed interest in being in involved in this program.
- The Ministry of Water and Irrigation contracts with private consultants to provide advisor services in irrigation water management. Payment is based on the number of

farmers assisted by the advisor. This approach has been used in California to provide irrigation system evaluation services.

Will privatization of the IAS succeed? Only time will tell. If the pressures to improve irrigation water management continue to increase, and the pilot program is highly successful in helping farmers improve profits through better water management, then perhaps privatization will be successful. Two things will need to happen: 1) a very successful pilot program, and 2) discussions will need to be started with key farmers on developing a private IAS program. It may also take a number of years, perhaps five or more, of a successful pilot program to attract sufficient interest in continuing the program as a private enterprise.

TECHNICAL REPORT

Review of Crop Water Requirements

I met with personnel of ARD and MWI to discuss efforts to determine crop water requirements for the Highland area. Their procedure is to calculate the reference crop evapotranspiration (ET) using the Penman-Monteith equation using data from weather stations located in the Highland area. According to ASCE Manual and Reports on Engineering Practice No. 70, *Evapotranspiration and Irrigation Water Requirements*, the Penman-Monteith is the most accurate of the combination methods.

Crop coefficients of the various crops grown in the Highland area are needed to calculate the actual crop ET. Crop coefficients being used by MWI/ARD are those reported in the recently published FAO 56, *Crop Evapotranspiration: Guidelines for computing crop water requirements.*

Based on the field evaluations, I recommended the following approach to using the FAO crop coefficients:

- All row crops are drip irrigated with the drip tubing is installed under plastic mulch. Soil evaporation should be minimal for those systems because no bare soil is wetting outside of the mulch. Thus, I recommended that the basal crop coefficients listed in FAO56 be used for the row crops. These basal crop coefficients also were found to be more similar to crop coefficients developed for subsurface drip irrigation in the San Joaquin Valley of California. Under subsurface drip irrigation, little soil evaporation is assumed to occur.
- Tree crops and most vine crops are irrigated with minibasins. These basins, 2 to 3 m in diameter, and installed around each tree and are irrigated using a high discharge rate emitter. I calculated an evaporation coefficient for a minibasins irrigating olive, which

resulted in a crop coefficient similar to the FAO56 single crop coefficients. Also, work by D. Goldhamer of the University of California, Davis, showed that under microsprinklers, the single crop coefficient was appropriate for olives. Based on these results, I recommended that the FAO single crop coefficient be used for trees and vines.

One concern, however, is that the crop coefficients for Vegetable Crops may be less than that used in FAO56 because of a smaller plant density used in the Highlands area. The FAO coefficients are similar to those used for the San Joaquin Valley of California where a bed spacing spacings of 1 to 1.5m are used. The canopy coverage of these systems is nearly 100 percent. However, the bed spacing used in the Highlands area for vegetable crops is 2 m, and thus, the plant density may be less compared with that used for the experiments used for the FAO56 values. This means that the crop water use in m^3/dunum of the Highland crops may be less compared with that calculated with the FAO56 coefficients. This matter should be investigated with some field evaluations.

Field Evaluations

Background

Irrigation efficiency is affected by the uniformity of the applied water and by the management of irrigation system. Management involves determining the amount of crop evapotranspiration between irrigations and then applying that amount plus any needed for leaching and irrigation system inefficiencies. Uniformity depends on the irrigation system design and maintenance.

The uniformity of drip irrigation systems depends on variations in emitter discharge rates throughout the field. These variations are caused by pressure changes throughout the field due to friction losses in pipelines, tubing, and fittings, clogging of emitters, and manufacturing variation in the emitters.

Uniformity of drip irrigation systems is frequently described by an index called the emissions uniformity (EU). The EU is defined as the minimum discharge rate divided by the average discharge rate. The minimum rate is defined as the average of the low quarter, or the average of the lowest one-fourth of the measured discharge rates. Field evaluations of microirrigation systems in California revealed that a field-wide EU of at least 80 percent is achievable. The significance of the EU with regard to irrigation efficiency is that the EU is an estimate the potential maximum irrigation efficiency if the least-watered area of the field receives that required for crop production, i. e. crop evapotranspiration, leaching, climate control.

Another index being promoted is the discharge ratio, which is the ratio of the maximum discharge rate to the minimum rate. This index is felt by some to better describe nonuniformity and is easier to comprehend by farmers.

Objectives of Field Evaluations

The objectives of the field evaluations are to determine the uniformity of irrigation systems in the Highlands area and to identify factors contributing to their performance. Observations also were made on any fertigation and chemigation (clogging prevention) practices. Eleven fields were used for this study covering a range of crop and qualitative estimates of irrigation efficiency made by a previous survey conducted by MWI/ARD personnel.

The procedure consisted of measuring discharge rates along laterals, lateral length, and tree and row spacings. Where possible, measurements were made along a lateral close to the inlet of a block or field and along a lateral located at the other side of a block or field. For the row crop laterals, two measurements were made at each distance along the lateral to identify any clogging problems. Pressure measurements were not made because of the lack of suitable fittings for pressure gauges. A pitot gauge was available, but it was decided that punching the holes in the tubing necessary to use the gauge should be avoided at this time.

Results

Table 1 shows the characteristics of the sites used for the field evaluations. The irrigation method used for tree crops was minibasin irrigation. This method consists of forming a basin, 2 to 3 m in diameter, around each tree. An adjustable emitter, one per basin, discharges water into the basin. However, at one site (#11), multiple drip emitters were used in the minibasins instead of the adjustable emitters. Lateral lengths ranged from about 50 m to 60-66 m.

Table 1. Characteristics of the sites used for the irrigation system evaluations.

No.	Site ID	Crop	Irrigation Method	Tree Spacing (m)	Row Spacing (m)	Emitter Spacing (m)	Lateral Length (m)
1	MF1129Q	Peach	M1[1]	4	4	4	70
2	MF1129Q	Grape	D[2]	3	4	0.4	50
3	MF3416Q	Apple	M1[1]	2	*	2	40
4	Al-1093	Olive	M1[1]	6	7	6	60-66
5	Al-1097	Olive	M1[1]	6	7	6	50
6	Al-3062	Apple	M1[1]	4	4	4	28
7	Al-3062	Squash	D[2]	*	2	0.4	50
8	Al-3062	Tomato	D[2]	*	2	0.4	50
9	Al-3080	Tomato	D[2]	*	2	0.4	50
10	Al-3082	Tomato	D[2]	*	2	0.4	50
11	Al-1088	Olive	M2[3]	8	8	8	64

[1] M1 = minibasin using adjustable emitter
[2] D = drip irrigation
[3] M2 = minibasins using drip emitters

Drip irrigation was used at Site 2, a vineyard. The drip system used in-line emitters installed in 16 mm tubing. Two lines of drip tubing, each 50 m long, were used for each vine row.

Drip irrigation was used for all row crops. The lateral length was 50 m at each row crop site. Drip tubing (16 mm diameter) with in-line emitters spaced 0.4 m apart was used at each site. The design emitter discharge rate was 4 l/h.

Evaluations results, listed in Table 2, show the average emitter discharge rate, maximum and minimum discharge rates, discharge ratio, and the emissions uniformity. Data from the evaluations are in Appendix A.

Table 2. Results of the evaluations of the irrigation systems.

No.	Site ID	Crop	Irrigation Method	Average Emitter Discharge Rate (l/h)	Maximum Emitter Discharge Rate [6] (l/h)	Minimum Emitter Discharge Rate [6] (l/h)	Discharge Ratio	E.U (%)
1	MF1129Q	Peach	M1	79.4	144.0	36.0	4.0	57[3]
2	MF1129Q	Grape	D	5.1	37.8	0.7	54.0	26[3]
3	MF3416Q	Apple	M1	56.7	86.4	32.4	2.7	76[2]
4	Al-1093	Olive	M1	69.5	120.0	36.0	3.3	62[3]
5	Al-1097	Olive	M1	67.0	84.0	48.0	1.8	83[3]
6	Al-3062	Apple	M1	72.6	93.6	52.2	1.8	72[3]
7	Al-3062	Squash	D	1.6	2.5	0.9	2.8	61[4]
8	Al-3062	Tomato	D	2.3	2.6	2	1.3	89[5]
9	Al-3080	Tomato	D	2.9	3.8	2.5	1.5	90[5]
10	Al-3082	Tomato	D	2.8	3.1	2.4	1.3	86[5]
11	Al-1088	Olive	M2	51.5	76.5	21.9	3.5	59[5]

[1] Adjustable emitters used in minibasins
[2] Drip Emitters used in minibasins
[3] Block wide EU
[4] Field wide EU; Lateral EU's were 84 and 88 percent for inlet and end laterals, respectively.
[5] Lateral EU
[6] Values are the average of the two of four highest and lowest values.

Tree Crops

A variety of results were found for the minibasin systems (Table 2). Emission uniformities ranged from 57 percent to 83 percent, while discharge ratios ranged from 1.8 to 4.0. The average discharge rate ranged from 51.5 l/h to 79.4 l/h. With the exception of Site 3, these EU's are block values. At Site 3, the EU represents measurements taken along two adjacent laterals.

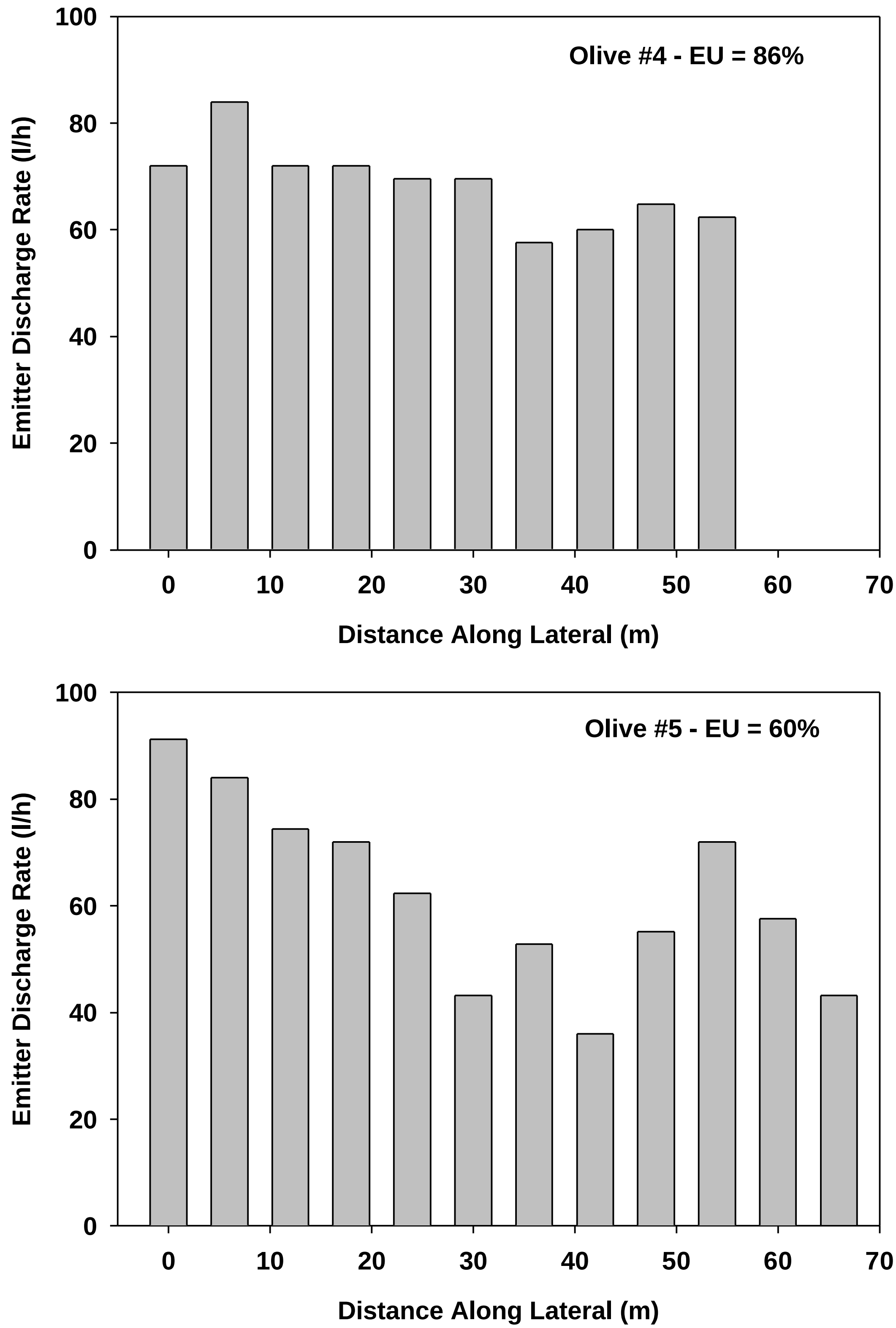

Figure 1. Emitter discharge rates versus distance along the lateral for Olive #4 and Olive #5.

Figure 1 shows emitter discharge rate versus distance along lateral for Sites #4 and #5. Little variability occurred at Site #5 compared to Site #4, reflecting the higher EU of Site #5. In general, lateral EU's ranged from 60 percent to 90 percent.

Hydraulic losses, elevation differences, clogging, and emitter discharge adjustments may affect variability in emitter discharge rates of the minibasin systems. I feel, however, that most of the variability is due to emitter adjustment, thus making any assessment of hydraulic losses difficult to make. For example, at one site, we found the discharge rate of a fully opened nozzle to be 108 l/h. There appears to be little clogging of these devices. For Site #5, careful nozzle adjustment appears to have occurred, reflected in the EU of nearly 83 percent.

The basin design means that that the tree uses all of the water applied to a basin. Any lateral redistribution of water in the soil from one basin to another is probably nil. Since for a given lateral, all basins have the same irrigation set time, the larger the discharge ratio, the more the water applied to the basin with the maximum discharge rate compared with that of the minimum discharge rate. For example, at Site 1 (peach), four times more water was applied in the basin receiving the most water compared to the basin receiving the least amount of water.

One site (#11) used drip emitters in the minibasins instead of the adjustable emitters. Each basin had a large drip emitter and six smaller emitters. The combined EU of an uphill and a downhill lateral was 59 percent. Discharge rates of the large emitter ranged from 13.4 l/h to 66 l/h. Clogging was observed among many of the smaller emitters. Leaks were also observed, the result of rodents chewing on the tubing. An attempt to plug the leaks was made by placing a sleeve of tubing over the leak. However, this was not effective. Goof plugs would be more effective in plugging leaks.

The results of the minibasin irrigation evaluations suggests that acceptable levels of uniformity can be achieved, and that this irrigation method using the adjustable nozzles may be more preferable for trees and vines than drip irrigation. I recommend that drip emitters not be used because of their potential or clogging, as found at Site #11. Good uniformity, however, will be obtained only if irrigators use care in adjusting emitter discharge rates by measuring the time to fill a container with a known volume. Some variation in discharge rates will occur, however, because of manufacturing variation (unknown) and because the adjustment of one emitter during an irrigation can slightly affect the discharge rates of other emitters along the lateral length.

While acceptable uniformity might be achieved with minibasin irrigation, their irrigation efficiency will also depend on the management of the system. At Site 3, the depth of ponding in the basin immediately following an irrigation was about 102 to 152 mm. Moss was observed growing in the basins. These observations suggest that considerable overirrigation might be occurring which would result in low irrigation efficiency even though the EU of 76 percent was fair.

On the other hand, at Site #5, the depth of water ponded in the basins was not measurable because of small applications of water, suggesting possible deficit irrigation. A severe problem in pressure nonuniformity throughout this field also appeared to occur. The farmer indicated that a set time of 30 minutes was used near the pump and a time of 60 minutes at the furthermost distance from the pump.

Several locations filled the basins with volcanic gravel mulch. This practice should help reduce evaporation of water from the soil, particularly for young trees.

Vineyard Drip System

The drip system evaluation consisted of measuring emitter discharge rates at selected distances along two laterals, one at the submain inlet and the other at the distal end of the submain. At each measurement location, two emitters were sampled, one on each side of the vine row. The drip tubing was about 8 years old.

The drip system had the lowest EU (25.5 percent) and the highest discharge ratio (54.0) of all of the irrigation systems evaluated.

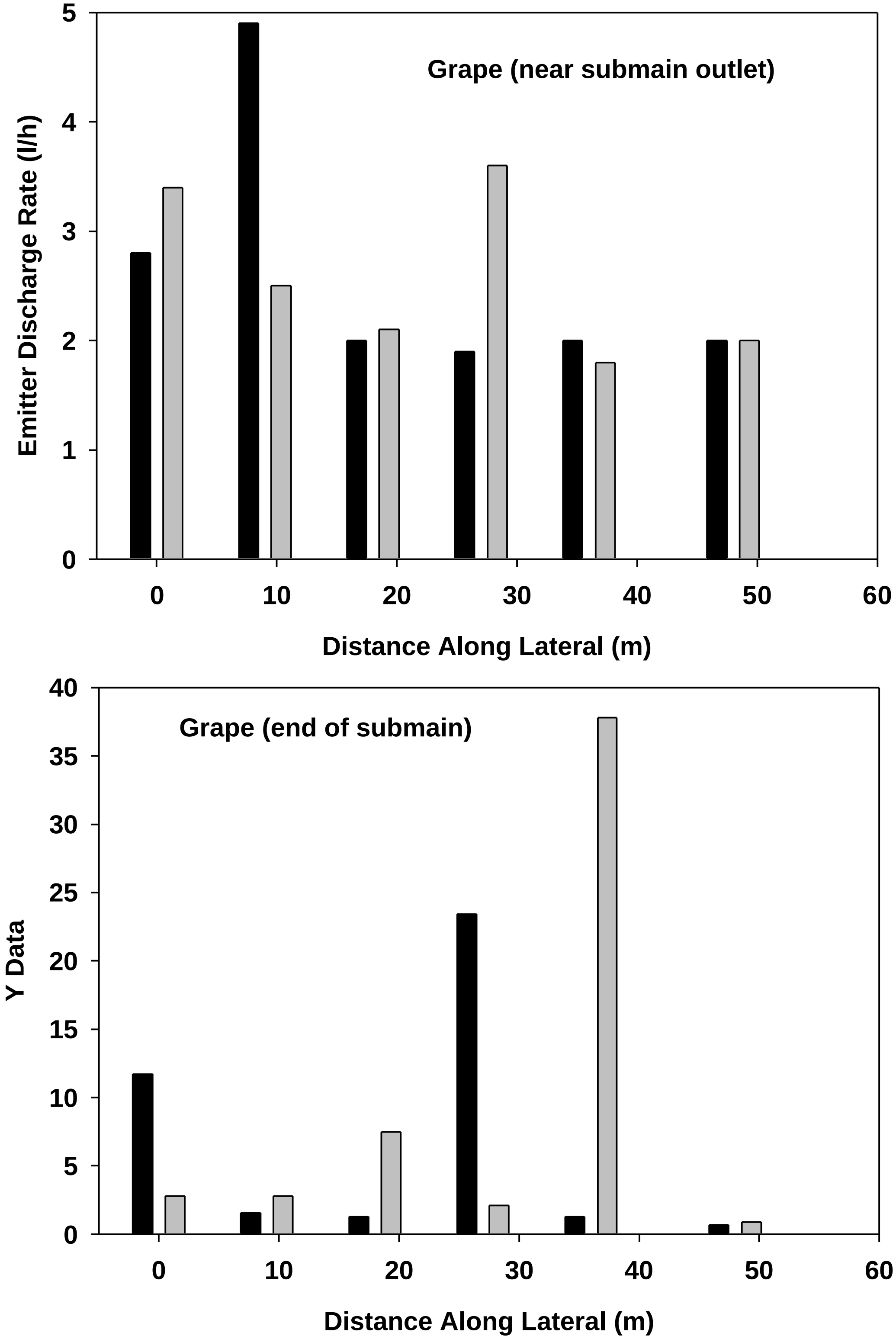

Figure 2. Emitter discharge rates along lateral length for the vineyard.

Figure 2 shows discharge rates along lateral length for the two sets of measurements. Clogging and malfunctioning emitters caused the poor uniformity. Along both laterals, some of the emitters emitted a jet of water, suggesting that the emitter flow passages were being partially bypassed by the water. Reasons for this behavior are unknown, but perhaps particles of some kind have become lodged between the molded plastic emitter and the tubing wall, thus resulting in a much larger flow passage for the water. The relatively small emitters discharge rates suggest clogging. Numerous leaks were also observed along both laterals.

There appears to be no maintenance program for this drip system to prevent clogging. Flushing of the laterals was not possible because of their design. The installation procedure used for this system was to lay tubing along one side of the vine row, loop the tubing around the end of the vine row at the end of the design length, and then continue laying the tubing along the other side of the vine row back to the submain. Thus, no outlet existed at the end of the lateral length for flushing.

The discharge ratio clearly shows the effect of the malfunctioning emitters, with 54 times more water being applied where the maximum discharge rate occurred compared with the minimum rate.

Row Crop Drip Irrigation

Drip lateral lengths were 50 m for all sites. Measurements were made every 5 m for all sites except Site 8. At this site, measurements were made every 10 m to limit exposure to the sulfur sprayed on the plants. Two measurements were made at each distance in an attempt to identify any clogging problems.

The evaluation results listed in Table 2 are lateral uniformities with the exception of Site 7. The small plant canopy at Site 7 allowed easy access to the drip emitters beneath the plastic mulch, and thus, measurements were made along a lateral near the field inlet and along a lateral on the other side of the field. For the tomato fields, mature plants existed, which made accessing the emitters beneath the plastic much more difficult, and thus, measurements were made only on one lateral per field.

For all laterals, high EU's were found, ranging from 86 to 90 percent, and discharge ratios were 1.3 to 1.5. This suggests that hydraulic losses along the laterals are small, and that the lateral length of 50 m is appropriate for the type of drip tubing and emitters used for these irrigation systems. No significant differences were found for laterals with water flowing downhill and those with water flowing uphill. At all sites except Site 10, new drip tubing was used.

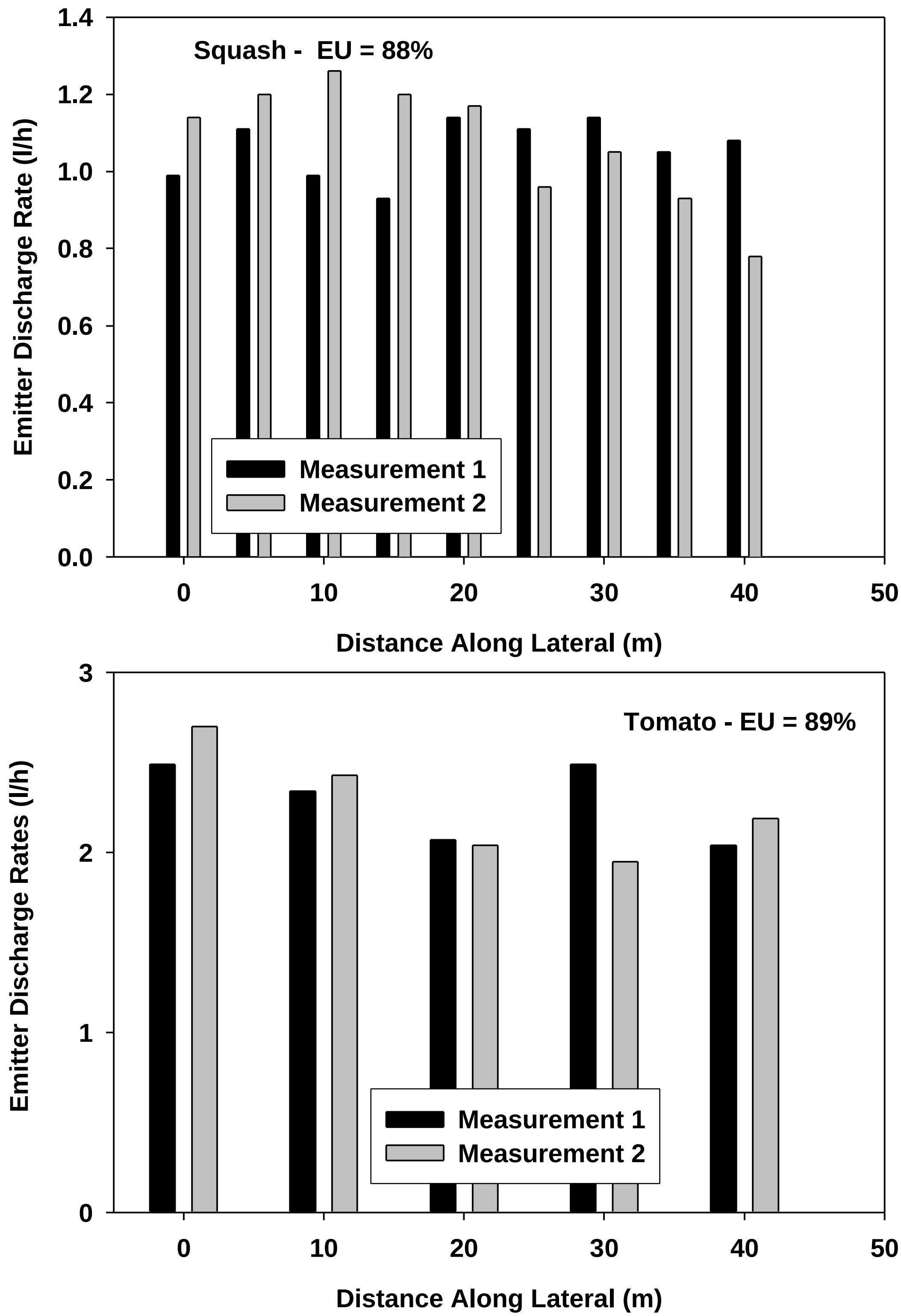

Figure 3. Emitter discharge rate versus distance along the lateral for two row crops.

Figure 3 shows emitter discharge rates along two laterals. At Site 10, actual EU's were less than the 86 percent shown in Table 2 due to clogging of some emitters. In calculating the EU shown in Table 2, the clogged emitters were not used in order to estimate the EU due to hydraulic losses only. The measurements showed that the emitters were either operating properly or clogged. At this site the drip tape was about 7 years old.

At Site 7, lateral EU's were high, 84 and 88 percent for the inlet and end laterals, respectively. However, the field wide EU was 61 percent and the discharge ratio was 2.8. The average discharge rate of the end lateral was 1.02 l/h, and was 2.13 l/h at the inlet lateral. These differences reflect pressure losses due to friction along the 240 m long submain and elevation differences between the two laterals. Since the entire field is irrigated at the same time, the area of the field near the inlet will receive more than twice the amount of water applied at the uphill end.

These data indicate a design problem in these drip systems. Insufficient pressure exists at the uphill end, and no pressure regulation occurs throughout the irrigation system. An approach to correcting this problem is the split the field into blocks using a manifold to irrigate each block. A pressure regulator installed in the inlet of each block will result in the same block pressure for each location along the submain. However, a booster pump of sufficient size will be needed to provide the desired pressure at the uphill end.

The behavior found at Site 7 could occur at Sites 9 and 10 because of the slopes at those fields along the submains. Designs similar to that used at Site 7 appear to be used at these sites.

It appears that the pressure at these sites is much less than the design pressure of the drip emitters. The design pressure is that which results in an emitter flow rate of about 4 l/h. However, the average discharge rates were much less that the design rate, indicating inadequate pressure at these sites.

Other Considerations

Several farmers indicated that they use or have used phosphoric acid to dissolve any carbonate precipitation in the emitters. While this acid will dissolve carbonate precipitates, it can also caused calcium phosphate precipitation if used improperly. One farmer indicated problems in using the acid.

The hazard with phosphoric acid is that if 40 to 50 ppm of calcium exists in the irrigation water, injecting phosphoric acid can cause a calcium phosphate precipitate to form. To prevent this precipitation, phosphoric acid should be injected at a rate sufficient to lower the pH to about 5. This will prevent precipitation of phosphates, and also dissolve any precipitated carbonate.

I observed that batch tanks are frequently used for fertigation. A batch tank is simply a cylinder that is filled with liquid fertilizer. Irrigation water flows into the bottom of the tank and displaces the fertilizer out of its top into the irrigation pipeline. A pressure drop is required between the water inlet and fertilizer injection point to force water into the tank.

This method of fertigation is commonly used because of its simplicity and low cost. However, the fertilizer solution in the tank becomes diluted with time, resulting in less and less chemical being applied. Thus, when irrigation sets are changed during an irrigation, batch tanks should be refilled to insure that the same amount of fertilizer is applied to each set.

Summary

These evaluations indicate that minibasin irrigation has the potential for acceptable uniformity. Its main advantage is that there is little maintenance required compared to drip irrigation. However, care is needed in adjusting the emitters such that little variation occurs among basins. Emitters can be adjusted by measuring the time required to fill a container of a known volume, but this procedure will be time consuming and not likely to be used by farmers. Perhaps, emitters with fixed discharged rates could be manufactured such that series of different nozzle sizes would be available over a discharge range of 60 to 80 l/h. It is recommended that drip emitters not be used with the minibasins because of their potential for clogging.

The lateral lengths used for row crop drip irrigation are properly sized, but a design problem exists in drip systems where slope occurs along the submains. Because of this slope and the lack of pressure regulation, considerably more water may be applied to some parts of the field compared with others. This can be changed using pressure regulation.

These evaluations clearly show the need for some type of technical assistance to farmers in the Highlands area. Farmers need to learn how to schedule irrigations, how to determine the amount of water needed for irrigation, and how to determine the amount much water applied to a field. Assistance is also needed in evaluating the performance of their irrigation systems and in improving system design.

Educational Materials

Need for a Program

Irrigation water management is a complex process involving areas such as soil-plant-water interactions, water quality, irrigation system design and maintenance, and crop evapotranspiration. Yet, my experience has been that many if not most farmers have had little education in the many aspects of water management. The four days of evaluations in the Highland area indicates that these farmers need some type of educational programs, as do farmers elsewhere. These programs are particularly needed in areas experiencing limited water supplies, poor water quality, and/or where adverse environmental impacts occur as a result of irrigation.

Type of Program

An educational program should use those techniques that effectively teach farmers about irrigation water management. It has been my experiences that programs such as slide presentations or PowerPoint presentations, commonly used by University of California Cooperative Extension personnel, may be informative, but they do not teach. Reasons for this included the limited amount of time generally used for these types of presentations and loss of audience contact and interaction by turning off the lights. Thus, I, along with some of my university colleagues, have developed educational program designed to teach farmers about the principles of irrigation water management such that they can apply these principles to their site-specific situations.

The program has two components:

- developing manuals on irrigation water management designed for farmers,
- conducting workshops and demonstrations using the manuals as texts where appropriate.

To date, seven manuals have been written on drip irrigation of row crops, microirrigation of trees and vines, salinity, pumps, surface irrigation, surge irrigation, and irrigation scheduling. Each manual consists of a series of short chapters such that each chapter can be used as a handout.

Experience has shown that while the manuals by themselves have been useful educational tools, some type of classroom instruction is still needed to teach farmers about procedures, techniques, etc. Simply providing handouts may not necessarily teach people about water management. Thus, we also conduct workshops designed to provided classroom instruction and field demonstrations for those interested in irrigation water management. The manuals have been used as texts for the workshops. Workshops have ranged from several hours up to about six hours. Results of these workshops have been highly positive.

A suggested educational program might consist of the following activities:

- Use short presentations such a slide shows, etc. to present information in a general manner.
- Conduct workshops to provide in-depth instruction and to give hands-on experience.
- Conduct field demonstrations to show how to install equipment, measure flow rates, show research results, check for emitter clogging, etc.
- Develop educational material on the various topics of irrigation water management. The material might consist of manuals, one-page handouts, and leaflets.

Appendix B contains a series of one to two page articles that have been modified from the material in the previously mentioned manuals. Some of the material can be used simply as handouts, but other topics should be taught, such as determining how much water has been applied, developing an irrigation schedule, using soil moisture sensors, etc. These materials are for the use of MWI/ARD for the programs that future studies and experiences show to be needed. They can be modified as needed to meet the needs of the Highlands farmers and others.

Developing an Irrigation Advisory Service Pilot Program

Need for a Pilot Program

Groundwater is the only source of irrigation water in the Highlands area of Jordan. Yet, there is little recharge to the aquifer in that area, and as a result, a severe groundwater overdraft is occurring. During the past few years, the overdraft problems have been aggravated by a continuing drought, which has almost eliminated any groundwater recharge from rainfall.

The evaluations and surveys conducted by MWI/ARD have clearly shown problems to exist in the management of irrigation water by farmers. Data on groundwater pumping suggest that in some cases, considerable overirrigation is occurring, while in other cases, deficit irrigation exists. Field evaluations have shown that farmers have little knowledge about the performance characteristics of their irrigation systems, and because of this lack of knowledge, some areas of field received much more irrigation water than do other areas. Thus, educating farmers about the aspects of irrigation water management is needed to improve irrigation efficiency in the Highlands areas.

Objective of the IAS Pilot Program

The objective of the IAS pilot program is to establish a program to help a small number of farmers in the Highland area improve their water management practices, and based on these results, evaluated the potential for expanding the program to reach a relatively large number of clientele.

Activities of the Pilot Program

This program should focus on a few farmers who would be willing to allow some changes to be made in their irrigation water management practices. Both educational and applied research activities should be part of this program. A list of possible activities is as follows.

Educational activities.

• Develop leaflets, handout material, and manuals of irrigation water management. These materials should be designed to help educate farmers on irrigation water management. Avoid educational material that is very general.

• Conduct workshops and field demonstrations to show techniques and methods of improved irrigation water management.

• Develop a mailing list of all farmers in the Highland area for distribution of educational information, announce of meetings, etc. (Note: this activity has been completed.)

• Coordinate with those farmers willing to participate in a pilot program in developing farm-level demonstrations and applied research projects.

Demonstration Activities

• Conduct field demonstrations to determine relationships between applied water and crop yield/quality. These studies should consist of applying irrigation water in amounts ranging from deficit irrigation to overirrigation to develop crop production functions for the crops grown in the Highlands area. Several years will be required to develop these relationships for tree crops.

• Demonstrate using soil moisture sensors to schedule irrigations. Criteria should include the instrument reading at which an irrigation should occur and placement of the instrument relative to the water source, i.e. drip tape, minibasins.

• A few farmers under irrigate investigates the economics of deficit irrigation versus adequate irrigation. This activity is suggested because some farmers are deficit irrigating their entire farm due to limited water supplies. Are they better off economically deficit irrigating the entire farm or reducing the irrigated area to that which can be adequately irrigated?

• Promote regulated deficit irrigation of trees and vines to determine the potential of this management approach for saving water. Regulated deficit irrigation has been investigated in Spain and the US as a management tool for water conservation. It involves deliberately under-irrigating trees at certain stages of growth. Research thus far has indicated that some tree crops can be stressed at certain stages of growth without adversely affecting yield. For example, during some growth stages of olive, water applications might be reduced by 50 percent without any yield loss.

• Develop crop coefficients for row crops that are appropriate for those cultural practices used in the Highland area.

• Investigate new materials for irrigation. For example, an adjustable emitter is used for minibasins irrigation. It may be possible that an emitter with a fixed discharge rates could be developed that will satisfy the irrigation requirements yet maintain a high level of field wide uniformity?

Procedure for Developing a Pilot Program

• Identify farmers who would be willing to participate in a pilot program. Based on the evaluations and surveys, farmers should be identified who might be willing to participate in a pilot program. The focus should be on tree crop farmers, but some row crop farmers should be included. My experience has shown that tree crop farmers are more likely to be willing to participate in this type of program. (Note: this activity has been completed by MWI/ARD.)

• Visit the farmers and explain the objectives and activities of the program. The farmers need to understand that participating in this program may require them to change some irrigation practices in a field or in part of field. Thus, there is some risk to them because some of the activities of this pilot program might reduce the yields of a small area of a field. (Note: this activity has been completed by MWI/ARD.)

• Hire personnel who are qualified and who can be adequately trained to be irrigation advisors. These people must be able to conduct field studies and to work with farmers. It is recommended as a minimum, irrigation advisors should have a bachelor's degree in civil/agricultural engineering, agronomy, plant science or some related field. The advisors needed to understand that it will be extremely important that they be seen frequently at the farms doing field research and conducting demonstrations and educational activities. Otherwise, the pilot program will probably fail.

• Develop contacts with the private sector that might be interested in being involved in the IAS pilot program and in continuing the IAS program after the pilot project is completed.

• Train the irrigation advisors in the principles of irrigation water management and in conducting farm level studies. This training might consist of classroom instruction and exercises follow by field activities involving evaluation irrigation water management practices of farmers. A suggested agenda for a training course is contained in Appendix C.

- Determine and purchase the equipment and support needed to conduct both educational and applied research activities. A field technician might be provided to assist the advisors in collected research data and in evaluating irrigation systems. A list of recommended equipment to start the pilot program is listed in Appendix D.
- Start the program by contacting the interested farmers and start installing instruments and conducting experiments.
- Conduct educational activities to disseminate the results of the program to all interested farmers. The mailing list should be used to contact all farmers about meetings, workshops, and field demonstrations.
- Expand the program as needed.

Developing a Private IAS Program

The long-term goal of the Irrigation Advisory Services Program is to eventually privatize the advisor program with farmers paying 100 percent of the program costs. The primary consideration for transforming the IAS program into a private program is, can an advisor generate sufficient income for salary and operating expenses.

Some options for developing a private IAS program are as follows:

- The advisor charges a fee only to those farmers who utilize his services. The fee could be based on number of dunums or on a per-site instrumented. In the US, private consultants providing irrigation scheduling services sometimes charge on a per acre basis or a per site basis. In the later case, a charge of $500 per access tube installed has been used for neutron moisture meter measurements. An irrigation company has expressed interest in being involved in this prgram.
- The Ministry of Water and Irrigation contracts with private consultants to provide advisor services in irrigation water management. Payment is based on the number of

farmers assisted by the advisor. This approach has been used in California to provide irrigation system evaluation services.

Will privatization of the IAS succeed? Only time will tell. If the pressures to improve irrigation water management continue to increase, and the pilot program is highly successful in helping farmers improve profits through better water management, then perhaps privatization will be successful. Two things will need to happen: 1) a very successful pilot program, and 2) discussions will need to be started with key farmers on developing a private IAS program. It may also take a number of years, perhaps five or more, of a successful pilot program to attract sufficient interest in continuing the program as a private enterprise.

It is may be inappropriate to apply the US experience to the Highlands situation. Most states in the US have a Cooperative Extension program that is affiliated with a major state university. The Cooperative Extension program consists of campus-based and county-based personnel. (Each state is subdivided into counties). These personnel are advisors to farmers in many areas including irrigation. This program has been highly successful, and Cooperative Extension personnel generally have a high degree of creditability with farmers.

In addition, there are many private consultants in California who provide irrigation services to farmers. In my opinion, they fall into three categories. First, some companies design and install irrigation systems. Most growers use these companies when installing new drip irrigation systems. Second, some companies provide analyses of soil and water. Third, other companies provide irrigation scheduling services to farmers. Farmers who use these consultants generally grow very high cash-value crops such as wine grapes, citrus, etc. or farm many thousands of dunums of land.

Many smaller farmers do not use private consultants for irrigation scheduling. Instead, these farmers frequently use the services of the University of California Cooperative Extension and the Natural Resources Conservation Service (USDA). There are no charges for the services of these agencies. A question is, if these agencies did not exist, would the smaller growers use private consultants for irrigation scheduling. The answer will probably depend to a large degree on the pressure farmers experience concerning irrigation water supplies.

Appendix A
Data of the Evaluations of Irrigation Systems

Site: Al – 3062.
Oulet lateral

Distance (M)	Time (Sec)	Vol. (ML)	Q
0	20	460	82.8
4	20	390	70.2
8	20	410	73.8
12	20	460	82.8
16	20	400	72
20	20	470	84.6
24	20	490	88.2
28	20	400	72

Second Lateral

Distance (M)	Time (Sec)	Vol. (ML)	Q
0	20	440	79.2
4	20	420	75.6
8	20	280	50.4
12	20	570	102.6
16	20	330	59.4
20	20	550	99
24	20	320	97.6
28	20	230	41.4

Squash –Aug. 20, 2000.
End Lateral

Distance (M)	Time (Sec)	Vol. 1 (ML)	Vol. 2 (ML)	Q1	Q2
0	120	33	38	.99	1.14
5	120	37	40	1.11	1.20
10	120	33	42	.99	1.26
15	120	31	40	.93	1.20
20	120	38	39	1.14	1.17
25	120	37	32	1.11	.96
30	120	38	35	1.14	1.05
35	120	35	31	1.05	.93
40	120	36	26	1.08	.78

Inlet Lateral

Distance (M)	Time (Sec)	Vol. 1 (ML)	Vol. 2 (ML)	Q1	Q2
0	120	76	68	2.28	2.04
5	120	82	87	2.46	2.61
10	120	77	64	2.31	1.92
15	120	82	82	2.46	2.46
20	120	64	65	1.92	1.95
25	120	70	69	2.10	2.07
30	120	56	75	1.68	2.25
35	120	60	58	1.80	1.74

Tomato – Aug. 20, 2000
Site AL - 3062

Distance (M)	Time (Sec)	Vol. 1 (ML)	Vol. 2 (ML)	Q1	Q2
0	120	83	90	2.49	2.70
10	120	78	81	2.34	2.43
20	120	69	68	2.07	2.04
30	120	83	65	2.49	1.95
40	120	68	73	2.04	2.19

Site: AL-3080
Tomato (FA) – Aug. 21, 2000

Downhill Lateral

Distance (M)	Time (Sec)	Vol. 1 (ML)	Vol. 2 (ML)	Q1	Q2
0	120	95	65	2.85	1.95
5	120	55	93	1.65	2.79
10	120	90	75	2.70	2.25
15	120	90	90	2.70	2.70
20	120	73	90	2.19	2.70
25	120	70	90	2.10	2.70
30	120	90	95	2.70	2.85
35	120	95	90	2.85	2.70
40	120	92	100	2.76	3

Uphill

Distance (M)	Time (Sec)	Vol. 1 (ML)	Vol. 2 (ML)	Q1	Q2
0	120	80	90	2.40	2.7
5	120	70	50	2.10	1.5
10	120	90	92	2.70	2.8
15	120	105	92	3.15	2.8
20	120	100	92	3	2.8
25	120	102	92	3.1	2.8
30	120	128	104	3.8	3.1
35	120	120	134	3.6	4
40	120	72	134	2.2	4

Site : AL-8082
Tomato (Talel M) – 7 Years old emitter

Downhill

Distance (M)	Time (Sec)	Vol. 1 (ML)	Vol. 2 (ML)	Q1	Q2
5	120	99	98	2.97	2.94
10	120	0	91	0	2.73
15	120	90	92	2.70	2.76
20	120	75	0	2.25	0
25	120	79	80	2.37	2.40
30	120	101	100	3.03	3
35	120	80	0	2.40	0
40	120	95	94	2.85	2.82

Uphill

Distance (M)	Time (Sec)	Vol. 1 (ML)	Vol. 2 (ML)	Q1	Q2
0	120	102	0	3.06	0
5	120	102	103	3.06	3.9
12	120	100	101	3	3.03
18	120	99	110	2.97	3.30
24	120	90	90	2.70	2.70
30	120	100	92	3	2.76
36	120	82	85	2.46	2.55
42	120	98	94	2.94	2.82

Site: AL-1088
Olives – Aug. 21, 2000
Drip emitter used in basics long large

Emitter & 6 small emitters

Downhill

Distance (M)	Time (Sec)	Large (ML)	Small (ML)	Large	Small	Total
0	120	636 (60sec.)	166	38.2	5.0	43.2
16	120	550 (30sec.)	350	66.0	10.5	76.5
32	120	445	284	13.4	8.5	21.9
48	120	615	61	36.9	1.8	38.7

Uphill

Distance (M)	Time (Sec)	Large (ML)	Small (ML)	Large	Small	Total
16	120	232 (15sec)	327	55.7	9.8	65.5
32	120	166 (15sec)	788	39.58	23.6	63.4

Site: MF 1129Q (Peach)

Lateral No. 1

Distance (M)	Time (Sec)	Vol. * (ML)	Q *
0	50	900	64.8
16	30	520	62.4
32	30	500	60.0
48	30	300	36.0
64	30	340	40.8

Lateral No. 2

Distance (M)	Time (Sec)	Vol. * (ML)	Q *
0	23	700	109.6
8	20	780	140.0
16	30	1200	144.0
24	30	670	80.40
32	30	520	62.40
40	30	680	81.60
48	30	570	68.40
56	30	680	81.60
64	30	550	66.0

***Vol.: Volume**
***Q : Emitter discharge rate.**

Site: MF-11290 (Grape)

Lateral No. 1

Distance (M)	Time (Sec)	Vol. 1 (ML)	Vol. 2 (ML)	Q1	Q2
0	120	92	112	2.8	3.4
9	120	164	54	4.9	2.5
18	120	66	70	2.0	2.1
27	60	32	60	1.9	3.6
36	60	34	31	2.0	1.8
48	120	67	68	2.0	2.0

Lateral No. 2

Distance (M)	Time (Sec)	Vol. 1 (ML)	Vol. 2 (ML)	Q1	Q2
0	30	380	92	11.7	2.8
9	120	52	93	1.6	2.8
18	120	44	250	1.3	2.5
27	60	390	70	23.4	2.1
36	120	42	630	1.3	37.8
48	120	24	30	0.7	0.9

Site: MF3416Q (Apple)

Lateral No. 1

Distance (M)	Time (Sec)	Vol. * (ML)	Q *
0	15	230	63.3
4	15	210	86.4
8	15	228	59.7
12	15	230	62.4
16	15	236	48.4
20	15	202	56.6
24	15	260	55.2
28	10	166	54.7
32	10	240	48.2
36	10	176	55.2

Lateral No. 2

Distance (M)	Time (Sec)	Vol. * (ML)	Q *
0	10	200	72.0
4	10	141	50.7
8	15	260	62.4
12	15	243	58.3
16	15	250	60.0
20	15	232	55.6
24	15	135	32.4
28	15	153	36.7
32	15	250	60.0

***Vol.: Volume**
***Q : Emitter discharge rate.**

Site: AL-1093 (Olives)

Lateral No. 1

Distance (M)	Time (Sec)	Vol. * (ML)	Q *
0	15	330	79.2
6	15	370	64.8
12	15	500	120.0
18	15	300	72.0
24	15	480	115.2
30	15	300	72.0
36	15	170	40.8
42	15	--	No Tree
48	15	300	72.0
54	15	220	52.8
60	15	400	96.0
66	15	--	No Tree

Lateral No. 2

Distance (M)	Time (Sec)	Vol. * (ML)	Q *
0	15	180	91.2
6	15	240	84.0
12	15	300	74.4
18	15	230	72.0
24	15	150	62.4
30	15	220	43.2
36	15	180	52.8
42	15	260	36.0
48	15	300	55.2
54	15	310	72.0
60	15	350	57.6
66	15	380	43.2

***Vol.: Volume**
***Q : Emitter discharge rate.**

Site: AL-1097 (Olives)

Lateral No. 1

Distance (M)	Time (Sec)	Vol. * (ML)	Q *
0	15	310	74.4
6	15	310	74.4
12	15	350	60.0
18	15	320	76.8
24	15	200	48.0
30	15	300	72.0
36	15	270	64.8
42	15	230	55.2
48	15	300	72.0
54	15	240	57.6

Lateral No. 2

Distance (M)	Time (Sec)	Vol. * (ML)	Q *
0	15	300	72.0
6	15	350	84.0
12	15	300	72.0
18	15	300	72.0
24	15	290	69.6
30	15	290	69.6
36	15	240	57.6
42	15	250	60.0
48	15	270	64.8
54	15	260	62.4

***Vol.: Volume**
***Q : Emitter discharge rate.**

APPENDIX B
Educational Material

EVAPOTRANSPIRATION AND CROP YIELD

What is Evapotranspiration?

Evapotranspiration, the water used by plants, consists of two components: transpiration and evaporation. *Transpiration* is water evaporation from plant leaves. *Evaporation* is water evaporation from the soil surface. Because it is difficult to measure the two components separately, they are combined into one term. At least 95 percent of the water taken up by plants is lost by transpiration.

When the crop is small, much of the soil surface is exposed to sunlight, and thus, evaporation will be more than transpiration. As the plant grows, more and more of the plant canopy covers the soil surface, and transpiration becomes greater than evaporation. For fully mature plant, evaporation is very small compared with transpiration.

What Affects Evapotranspiration?

Solar radiation is the primary source of energy for evapotranspiration. Increased solar radiation increases the potential for transpiration. The amount of solar radiation depends on the time of day, time of year, latitude, and cloud cover. Daily solar radiation increases with time of day to a maximum at about noon during the summer in a hot, arid climate. On cloudless days, about 70 to 80 percent of the sun's radiation (direct radiation) reaches the earth's surface directly. On cloudy days, most solar radiation is direct radiation scattered by the atmosphere.

Wind can affect evapotranspiration considerably. Air blowing over a dry surface picks up heat. The heated air blowing over an irrigated field heats the leaves, causing increased transpiration. The effect of heated air on crop growth is more noticeable at the edge of the field than inside the field. Plants at the edge of the field can be stressed while plants elsewhere are not.

Other climatic factors affecting evapotranspiration are humidity and temperature. The higher the temperature, the higher the evapotranspiration. On the other hand, the higher the humidity, the lower the evapotranspiration. Thus, evapotranspiration in humid areas will be less compared with arid areas given the same temperature, wind, and solar radiation.

How Does Evapotranspiration Affect Crop Yield?

As evapotranspiration increases, crop yield also increases. Maximum crop yield occurs when evapotranspiration is maximum, which is determined by climatic conditions. This behavior occurs for all crops, even for those crops that only part of the plant material is harvested such as tomato, cauliflower, etc.

What Causes Crop Evapotranspiration to be Less Than Maximum?

Many factors such as inadequate nutrients, salt, disease, and insect damage can reduce the growth of a plant, and thus, reduce evapotranspiration. However, the most significant factor responsible for reducing evapotranspiration is insufficient soil moisture. Insufficient soil moisture results in adverse levels of water stress in a plant, thus reducing the evapotranspiration, and eventually, crop yield. The effect of reduced levels of soil moisture on crop yield depends on the type of crop. Generally, yields of most vegetable crops are severely affected by insufficient soil moisture and reduced evapotranspiration.

HOW MUCH WATER AM I APPLYING?

To determine how long you should irrigate, use the following equation. Information needed is the flow rate in cubic meters per hour, the dunums irrigated, and the irrigation time in hours.

$$D = Q \times T / A$$

D = average millimeters (mm) of water applied to the field
Q = flow rate in cubic meters per hour
T = hours required to irrigate the field
A = dunums irrigated

Example: Determine the millimeters applied to 2 dunums in four hours. The flowrate is 3.5 cubic meters per hour.

D = 3.5 cubic meters per hour x 4 hours / 2 dunums = 7 mm

HOW LONG SHOULD I IRRIGATE?

To determine how long you should irrigate, use the following equation. Information needed is the dunums irrigatede, the millimeters of water needed to be applied, and the flow rate in cubic meters per hour.

$$T = A \times D / Q$$

D = average millimeters (mm) of water applied to the field
Q = flow rate in cubic meters per hour
T = hours required to irrigate the field
A = dunums irrigated

Example: Determine the hours needed to apply 8 mm of water applied by a drip irrigation system irrigating grapes for a flowrate of 4 cubic meters per hour. The area irrigated is 8 dunums. .

T = 8 dunums x 8 mm / 4 cubic meters per hour = 16 hours

WHAT IS A MILLIMETER OF WATER?

Units commonly used for describing the volume of water are cubic meters and liters. In agriculture, however, depth of water frequently is used to describe water use. The depth (D) is defined as a volume (V) of water divided by the area (A) over which the water is distributed. Use of a depth of water standardizes water use in agriculture, making it independent of field area.

Units commonly used for area are dunum and hectare, and for volume, hectare-meters. Thus, one hectare meter equals a volume of water ponded one meter deep over an area of one hectare. The depth of water is the ratio of the volume in hectare-meters to the number of hectares being irrigated. Units normally used for depth are millimeters or meters.

Some conversion factors are:

1 dunum = 1,000 m^2

1 hectare = 10,000 m^2

1 hectare = 10 dunums

1 meter = 1,000 millimeters

1 m^3 = 1,000 liters

AVAILABLE SOIL MOISTURE

What is Available Soil Moisture?

Available soil moisture is moisture that plants can use. It depends on soil texture. The upper limit of available soil moisture is the field capacity, defined as the soil moisture at which drainage ceases. Field capacity occurs at soil moisture tensions of 10 centibars for sandy soil and 33 centibars for other soil. The lower limit is the wilting point, defined as the soil moisture at which plants wilt permanently. Permanent wilting point occurs at 15 bars or 1500 centibars. Table 1 list average values and ranges of available soil moisture for various soil textures.

Total available soil moisture in the root zone is available soil moisture obtained from Table 1 multiplied by root depth.

Table 1. Soil moisture content in millimeters s of water per meter of soil at field capacity, 15 bars, and available soil moisture for various soil textures.

Soil Texture Content	Field Capacity	15 Bars	Available Moisture
Sand	100	42	58
Loamy Sand	142	58	84
Sandy Loam	192	83	109
Loam	267	117	150
Silt Loam	300	133	167
Sandy Clay Loam	250	150	100
Sandy Clay	242	150	92
Clay Loam	317	192	125
Silty Clay Loam	358	200	158
Silty Clay	408	267	141
Clay	392	258	134

WHAT IS SOIL?

What is Soil?

Soil consists of mineral particles--organic matter, air, and water. The mineral particles are classified as sand, silt, and clay. Sand particles are the largest size, and the clay particles, the smallest. The relative proportion of these sizes determines the soil texture.

Soil texture affects the water-storage capacity of soil and the rate at which water infiltrates into and flows through soil--all characteristics important for irrigation water management. Sandy soil stores a relatively small amount of soil moisture but has high infiltration rates. Clay soil stores much moisture, but has slow infiltration rates.

What are the Soil Textural Classes?

Soil is frequently designated as “coarse-textured” or “fine-textured.” Table 1 assigns the textural classes to broad categories of coarse-, medium-, and fine-textured soil.

Table 1. Soil textural classes.

General Terms	**Textural Classes**	**Soil Type**
Sandy soils	Coarse-textured soils	Sands
		Loamy sands
Loamy soils	Moderately coarse-textured soil	Sandy loam
		Fine sandy loam
	Meduim-textured soils	Very fine sandy loam
		Loam
		Silt loam
		Silt
		Clay loam
	Moderately fine-textured soils	Sandy clay loam
		Silty clay loam
Clayey soils	Fine-textured soils	Sandy clay
		Silty clay
		Clay

How to Identify Your Soil Type?

In the field, soil texture is determined by feeling the soil. Some general definitions of soil textural classes are as follows:

- Sand is loose and single grained. The individual grains can be seen or felt readily. Squeezed in the hand when dry, sand falls apart when pressure is released. Squeezed when moist, it forms a cast but crumbles when touched.

- A sandy loam is soil containing a high percentage of sand but having enough silt and clay to make it somewhat cohesive. The individual sand grains can be readily seen and felt.

Squeezed when dry, a sandy loam forms a cast that falls apart readily. If squeezed when moist, a cast can be formed that bears careful handling without breaking.

- A loam is soil having a relatively even mixture of sand, silt, and clay. It is mellow with a somewhat gritty feel, but is fairly smooth and slightly plastic. Squeezed when dry, it forms a cast that requires careful handling. The cast formed for squeezing a moist soil can be handled freely without breaking.

- A silt loam is soil having a moderate amount of fine sand and only a small amount of clay; over half of the particles are classified as silt. When dry, a silt loam appears cloddy, but the lumps can be broken readily. When pulverized, it feels soft and floury. Either dry or moist, it forms a cast that can be handled freely without breaking. When moistened and squeezed between the thumb and finger, it does not ribbon but has a broken appearance.

- A clay loam is a fine-textured soil that usually breaks into clods or lumps that are hard when dry. When the moist soil is squeezed between the thumb and finger, it forms a thin ribbon that breaks readily. The moist soil is plastic and forms a cast that bears much handling.

- A clay is fine-textured soil that usually breaks into clods or lumps that are hard when dry. It is very plastic and sticky when wet. When the moist soil is squeezed between the thumb and finger, it forms a long, flexible ribbon.

What is Tilth?

The physical condition of the soil as related to plant growth and ease of tillage is called the tilth. Tilth depends on the soil granulation and stability of granules, aeration, and soil moisture content. Tilth can be seriously impaired by improper plowing and cultivation. Soil in good tilth are mellow, crumbly, and easily worked. Soils in poor tilth are hard, cloddy, and difficult to work. Another common term related to tilth is friable.

WHAT IS SOIL MOISTURE AND SOIL MOISTURE TENSION?

What is Soil Moisture?

Soil contains solid particles-sand, silt, and clay-and voids or pores. The pores contain air and water. Void or pore volume, ranges from about 30 percent in sand to about 50 percent in clay of the total volume of soil. Clay has more pore volume than sand, but the pores are smaller because of the smaller particle sizes of clay. Sand has larger pore sizes because of larger particle sizes. Both pore volume and pore size play major roles in water movement and water retention or water-holding capacity of soil.

Saturated soil has pores completely filled with water. No air can flow through the soil. Unsaturated soil has pores partially filled with water so that air can flow though the soil. The amount of water in soil is the soil moisture content.

Gravity drainage and crop use of soil moisture drains water out of the pores. This causes a saturated soil to become unsaturated. The largest pores empty first followed by progressively smaller pores emptying as drainage continues. Thus, the remaining soil moisture occupies the smaller pores, and as drainage continues, soil moisture decreases and is retained in progressively smaller pores.

Soil moisture content is normally described as millimeters of water per meter of soil depth.

What is Soil Moisture Tension?

Soil moisture tension is a measure of the energy that keeps the water in soil. As soil dries, soil moisture tension increases. The amount of soil moisture content keep in the soil at a particular soil moisture tension, however, depends on soil texture. For a given soil moisture tension, soil moisture content of a sandy loam will be less than that of clay loam.

WHEN SHOULD I IRRIGATE?

Irrigations should occur before soil moisture depletions are severe enough to reduce crop yield. A plant can deplete a certain amount of soil moisture without reducing yield. If, however, too much moisture depletion occurs, plants can experience severe water stress, and then yields will be reduced. Thus, soil moisture depletions are limited to those that cause no yield loss. Instruments such as tensiometers or Watermark blocks are methods that can be used to determine possible adverse soil moisture conditions**.**

In surface and sprinkler irrigation scheduling, irrigations take place when the crop evapotranspiration equals the allowable soil water depletion level—the maximum amount of water that can be depleted from the soil in a particular crop without reducing yield. For these irrigation systems, however, much of the soil is wetted, and thus, roots are distributed throughout the wetted soil.

Under drip and minibasin irrigation, a different approach must be used. Only a small amount of the soil is wetted during irrigation with the soil being wettest near the drip emitters or the basin. Roots are then concentrated in the wet soil. Beyond the wetting pattern, little wetting occurs, and few roots are found there.

Under drip irrigation, irrigations should be quite frequent in order to keep soil water content at a fairly constant level. Because the root zone in drip-irrigated crops is limited to the wetted soil area, making much less of the soil water readily available to the crop, irrigation must be more frequent under drip irrigation than under furrow or sprinkler irrigation.

A recommended irrigation frequency for drip irrigation of row crops is about twice per week. Less frequent irrigations could reduce crop yield. For minibasin irrigation of trees, irrigate at least once per week.

Because the amount of soil wetted by drip irrigation or minibasin irrigation is small compared to other irrigation methods, the amount of water that can be stored in the soil also is small. Thus, to prevent overirrigation, small applications of water must be used. Applying the right amount of irrigation water means that both the crop evapotranspiration between irrigations and the emitter discharge rate must be known. A procedure for determining how much water to apply is in ____________________.

HOW DO YOU MEASURE SOIL MOISTURE?

Measuring or monitoring soil moisture is recommended even if crop water use data are available. Site-specific conditions such as soil texture, root depth, and climate may cause actual evapotranspiration to differ from calculated values. Thus, measuring soil moisture content can help evaluate any effects of site-specific conditions on crop growth.

Many methods for measuring or monitoring soil moisture content are summarized as follows:

<u>Soil probe/soil sampling</u>. Soil samples are obtained using a soil probe or auger. Appearance and feel of the soil is related to soil moisture using an appropriate chart. Soil samples can also be dried in an oven to determine actual soil moisture

<u>Tensiometers</u>. A tensiometer is a plastic tube with a porous cup attached to one end and a vacuum gauge attached to the other end. The porous cup is inserted into the soil, and the vacuum gauge measures the soil moisture tension. Tensiometers measure soil moisture tension

Watermark Blocks. These devices are two electrodes embedded in a gypsum-ceramic mixture. Changes in soil moisture content cause changes in the water content of the block which in turn changes its electrical resistance. An appropriate instrument is used to read the electrical resistance or conductance of the block. Readings of resistance blocks are related to soil moisture tension.

TENSIOMETERS

What is a Tensiometer?

A tensiometer—a device for measuring soil moisture tension—is a cylindrical pipe about 25 mm in diameter with a porous ceramic cup attached to one end and a vacuum gauge attached to the other (Figure 1). The porous cup allows water to flow in and out of the tensiometer as soil moisture content changes. The vacuum gauge readings, which measure soil moisture tension, change in response to this water flow. Units of gauge readings for commercially made tensiometers frequently are in centibars, with the vacuum gauge ranging between 0 and 100 centibars. A reservoir is located at the top of the tensiometer. The tensiometer must be sealed tightly to prevent air from entering to operate properly.

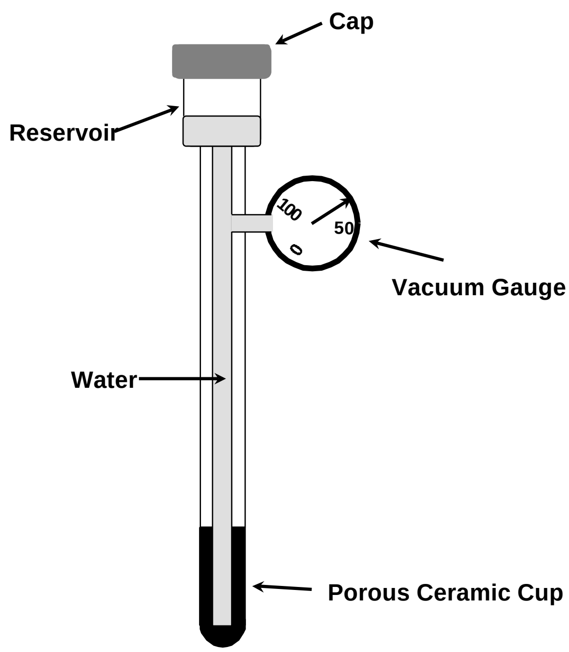

Figure 1. Tensiometer.

Tensiometers are easy to install, read, and maintain. They provide information on soil moisture tension which helps irrigators determine when to irrigate.

How Do Tensiometers Operate?

As soil dries, soil moisture content decreases and soil moisture tension increases. This decrease in soil moisture content causes water to flow out of the tensiometer through the porous cup, and the tensiometer gauge to read higher and higher. During irrigation, soil moisture content increases causing soil moisture tension to decrease and water to flow into the tensiometer. This causes tensiometer readings to decrease.

Water flows in and out of tensiometers only if the porous cup is saturated with water. If the cup desaturates, then little or no flow occurs, and air enters the tensiometer. The tensiometer then stops operating. The porous cup will desaturate if the soil becomes too dry.

To restore proper operation, tensiometers must be resaturated by filling the pipe and reservoir with water and flowing water through the porous cup for several hours before sealing the pipe. However, unless the soil is rewetted by an irrigation, the porous cup will rapidly desaturate again. Thus, tensiometer readings that drop to zero in dry soil do not necessarily indicate faulty instruments, but rather dry soil with moisture contents likely to reduce crop growth and yield of water-stress sensitive crops.

The maximum tensiometer reading at sea level are 80-85 centibars. Maximum readings decrease with altitude, and at about 1,000 m, the maximum is about 60 centibars.

A tensiometer may operate poorly in a very sandy soil. The coarseness of the sand may cause poor hydraulic contact between the porous cup and the soil. Thus, water will not readily flow in and out of the tensiometer resulting in a very slow response of the tensiometer to changes in soil moisture. One manufacturer markets a tensiometer that is designed to overcome this problem to some degree by using a relatively coarse porous cup.

How Do I Install a Tensiometer?

First, soak the tensiometer in water for several hours to saturate the porous cup. Next, make a pilot hole with a soil probe down to the desired depth. Pour a small amount of a slurry of soil and water into the pilot hole before inserting the tensiometer to ensure good hydraulic contact between soil and porous cup. Next, insert the end of the tensiometer with the porous cup into the pilot hole. Then fill the tensiometer with water, sealed it, and allowed it to equilibrate for about 24 hours before making readings. Install tensiometers at about one-fourth to one-third of the maximum root depth to schedule irrigations. Another tensiometer installed near the bottom of the root zone is recommended to monitor depth of wetting. Tensiometer readings at that depth that do not change after irrigation indicated that water is not infiltrating down to that depth.

Maintaining Tensiometers

Periodic maintenance is require for tensiometers. Periodically fill the tensiometer with water and replace porous cups and O-rings as needed. A cracked cup prevents a vacuum from occurring in the tensiometer causing the instrument to always read zero. A saturated porous cup should not be exposed to the atmosphere for long periods of time. Such exposure evaporates water from the cup's surface causing salt buildup and clogging. Copper sulfate or an algaecide may be needed to prevent algae growth in the tensiometer.

What Do The Readings Mean?

Tensiometer readings can be used to determine when to irrigate. Table 1 shows some suggested readings at which irrigations should occur. If irrigations are delay such that higher tensiometer readings occur between irrigations, crop yield reductions may occur.

Table 1. Some recommended tensiometer readings at which irrigations should occur.

Crop	Tensiometer Reading (centibars)
Cabbage	60-70
Cantaloupe	35-40
Citrus	50-70
Corn	50-80
Deciduous Tree	50-80
Grapes	
Early	40-50
Mature	70-80
Onion	45-65
Tomato	60-70

Where Can I Buy Tensiometers?

PROVIDE NAMES OF LOCAL DISTRIBUTORS OF TENSIOMETERS

WATERMARK BLOCKS

What are Watermark Blocks?

Watermark blocks measure the electrical resistance of the water in the blocks. They consist of two electrodes embedded in a porous, granular material (see Figure 1). A meter is used to read the blocks by attaching the wires extending from the block to the soil surface. The instrument provided for these blocks reads in centibars of soil moisture tension.

Watermark blocks are easy to install, read, and maintain. Because they are buried, damage by farming equipment, animals, etc. is minimal.

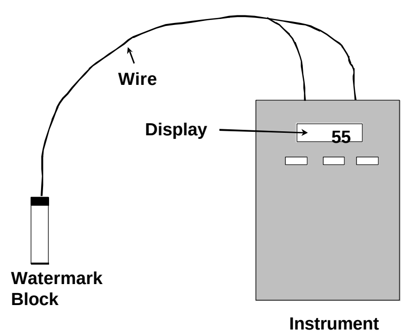

Figure 1. Watermark Block.

How Does a Watermark Block Operate?

Drying soil causes water to flow out of the Watermark block, which increases the electrical resistance of the water in the block. This is analogous to increasing the electrical resistance between two electrodes attached to a wire by using a smaller and smaller wire. Rewetting the soil causes soil water to flow into the block, thus, increasing the conducting area and decreasing its electrical resistance.

Electrical resistance of blocks also depends on the salinity of the block water. The gypsum in the block dissolving or precipitating as the block water content changes stabilizes salinity effects. These reactions maintain a constant electrical conductivity of the block water up to a point. If the salinity of the irrigation water becomes too high, then Watermark block readings will be affected.

How Do I Install Watermark Blocks?

First, soak blocks in water for a few minutes to saturate them. Then, make a small-diameter hole with a soil probe or a small-diameter auger to a depth slightly deeper than that desired. Next, add slurry consisting of water, a small amount of soil, and, if possible, gypsum to the hole to provide good contact between soil and block. Before installing a block, check the block reading to ensure that the block is working.

Push the block into the slurry in the bottom of the hole with a length of PVC pipe (1/2”, Schedule 80). Remove the pipe and backfill the hole with soil removed from the hole. Do not damage the wire leads during the backfilling. As the hole is filled, pack the backfilled soil in the hole with the PVC pipe. Be sure to identify each block with a tag or knots in the wire.

As a minimum, install one block at approximately one-fourth to one-third of the root zone to schedule irrigations and a block at the bottom of the root zone to monitor depth of wetting. Blocks installed at one-foot depth intervals, however, provide better information on depth of wetting and soil moisture uptake patterns. Little change in block readings at the lower depths after an irrigation indicates water did not reach those depths, and that there is little or no percolation.

What Do the Readings Mean?

Recommended soil moisture tensions at which irrigation should occur are in Table 1.

Table 1. Recommended tensiometer readings at which irrigations should occur.

Crop	**Watermark Block Reading (centibars)**
Cabbage	60-70
Cantaloupe	35-40
Citrus	50-70
Corn	50-80
Deciduous Tree	50-80
Grapes	
Early	40-50
Mature	70-80
Onion	45-65
Tomato	60-70

Problems in Coarse-Textured Soil

In very coarse-textured soils, the response of electrical resistance blocks may lag behind changes in soil moisture content caused be poor hydraulic contact between blocks and soil. Under these conditions, block readings may indicate little depletion of soil moisture even though severe drying of soil may occur.

Temperature Effects

The reading of an electrical resistance block also depends on the temperature of the soil. The electrical resistance decreases as the temperature increases. One manufacturer provides for adjustments for temperature while others do not.

Can I Use an Ohm Meter Instead of the Manufacturer’s Meter?

A question frequently asked is, “Can an ohm meter be used instead of the manufacturer’s meter?” The answer is no. Ohm meters use DC voltage. Applying DC power to resistance blocks causes polarization at the electrodes and results in unstable readings. The manufacturers’ meters convert DC to AC, which stabilizes the meter readings.

How Much Do They Cost?

The cost of resistance blocks range from about $6 to $20 depending on the manufacturer. The meter used to read all blocks may range in cost from $200 to $400.

Where Can I Buy Watermark Blocks?

Manufacturers of resistance blocks and meters include:

LIST LOCAL SOURCES FOR BUYING WATERMARK BLOCKS

MANAGING IRRIGATION WATER OF

DRIP-IRRIGATED TOMATO

Irrigation scheduling of drip irrigated tomato requires knowing the crop water use between irrigations and then applying that amount of water plus any required for irrigation inefficiencies. A step-by-step procedure is presented for managing irrigation water for drip irrigated tomato in the Highlands area. Information needed to use this procedure is the crop water use between irrigations and flow rate into the field.

1. Select an irrigation frequency not less than about twice per week.

2. Determine the daily crop water use in m^3/day/du using Table 1.

3. Determine the total crop water use between irrigations by multiplying the days between irrigations by the daily crop water use in Step 2.

Total Crop Water Use (m^3/du) = Daily Crop Water Use (m^3/du) x days between irrigations.

4. Determine the flow rate into the field (Q) in m^3/hour from flow meter measurements.

5. Calculate the application rate (AR) of the drip system in m^3/hour/du using the following:

$$AR\ (m^3/\text{hour-du}) = Q / A$$

where A = dunums irrigated at a time.

6. Calculate the hours needed (T) to apply the water used by the crop between irrigations using:

$$T = \text{Total Crop Water Use } (m^3/\text{du}) / \text{Application Rate } (m^3/\text{hour-du})$$

7. Adjust the irrigation time to account for the irrigation efficiency (IE) of the irrigation system. Do not use an irrigation efficiency less that 80 percent.

$$T_{adjusted} = 100 \times T / IE\ (\%)$$

Table 1. Daily crop water use (m3/day-du) of tomato in the Highlands area.

Month				
Jan				
Feb	1.8			
Mar	2.6	1.6		
Apr	4.0	3.7		
May	4.6	4.5		
Jun	5.0	4.7	1.7	
Jul	1.4	2.8	5.0	1.6
Aug			4.3	4.3
Sep			3.7	3.7
Oct			2.5	2.7
Nov			1.7	1.8
Dec				

Note: The values in Table 1 should be adjusted to the new crop water use values when they are available.

MANAGING IRRIGATION WATER
OF BASIN IRRIGATED OLIVE

Irrigation scheduling of basin-irrigated olive requires knowing the crop water use between irrigations and then applying that amount of water plus any required for irrigation inefficiencies. A step-by-step procedure is presented for managing irrigation water for basin-irrigated olive in the Highlands area. Information needed to use this procedure is the crop water use between irrigations and flow rate into the field.

1. Select an irrigation frequency not less than about once per week.

2. Determine the daily crop water use in m^3/day/du using Table 1.

3. Determine the total crop water use between irrigations by multiplying the days between irrigations by the daily crop water use in Step 2.

Total Crop Water Use (m^3/du) = Daily Crop Water Use (m^3/du) x days between irrigations.

4. Determine the flow rate into the field (Q) in m^3/hour from flow meter measurements.

5. Calculate the application rate (AR) of the drip system in m^3/hour/du using the following:

$$AR\ (m^3/hour\text{-}du) = Q / A$$

where A = dunums irrigated at a time.

6. Calculate the hours needed (T) to apply the water used by the crop between irrigations using:

$$T = \text{Total Crop Water Use } (m^3/du) \ / \ \text{Application Rate } (m^3/hour\text{-}du)$$

7. Adjust the irrigation time to account for the irrigation efficiency (IE) of the irrigation system. Do not use an irrigation efficiency less that 80 percent.

$$T_{adjusted} = 100 \times T / IE\ (\%)$$

Table 1. Daily crop water use (m3/day-du) of olive in the Highlands area.

Month	D	M	W
Jan	2.0	1.6	1.3
Feb	1.5	1.0	0
Mar	2.1	1.6	1.2
Apr	3.0	2.8	2.3
May	2.5	2.4	2.2
Jun	2.2	2.1	2.0
Jul	2.1	2.1	2.1
Aug	1.9	1.8	1.7
Sep	1.6	1.6	1.5
Oct			
Nov			
Dec			

Note: The values in Table 1 should be adjusted to the new crop water use values when they are available.

UNIFORMITY AND IRRIGATION EFFICIENCY

The uniformity of water describes how evenly irrigation water is distributed throughout a field. A uniformity of 100 percent would mean that the same amount of water is applied everywhere. Some irrigation systems have a potential for higher uniformity than others. But remember, all systems apply more water in some parts of a field than in others. Design and maintenance of an irrigation system help determine the degree of uniformity.

Irrigation efficiency is the average depth of water beneficially used divided by the average depth of irrigation water applied. Beneficial use includes water used for crop evapotranspiration, leaching for salinity control, climatic control, and system maintenance.

Distribution uniformity (DU) is the minimum depth infiltrated divided by the average depth infiltrated. The minimum depth is the lowest one-fourth of the measured infiltrated amounts.

DU estimates the maximum irrigation efficiency of a properly managed irrigation system, assuming surface runoff is efficiently used. The higher the DU, the higher the potential irrigation efficiency.

Many evaluations of irrigation systems revealed similar Dues for all systems. Even new drip irrigation systems generally had unsatisfactory Dues. However, a potential for a higher DU was found for properly designed and maintained drip systems.

Practical maximum irrigation efficiencies based on achievable high Dues are shown in Table 1 These values assume a properly managed system, the DU is a good estimate of efficiency, and that surface runoff is beneficially used.

Table1. Practical potential irrigation efficiencies.

Irrigation Method	Irrigation Efficiency (%)
Sprinkler	
Continuous-move	80 - 90
Periodic-move	70 - 80
Portable solid-set	70 - 80
Drip Irrigation	80 - 90
Furrow	70 - 85
Border	70 - 85

REGULATED DEFICIT IRRIGATION OF TREE CROPS

Normally, deficit irrigation is discouraged because of its potential adverse effect on crop yield. For some crops, however, regulated deficit irrigation uses less water with little or no effect on yield, and in some cases, benefits crop quality. Regulated deficit irrigation may be particularly beneficial during drought conditions or in areas with limited water supplies.

What is Regulated Deficit Irrigation?

Regulated deficit irrigation involves inducing water stress during periods of slow vegetative and reproductive growth by reducing applied water during those periods. During other growth stages, normal amounts of water are supplied to meet the full crop evapotranspiration demand. Tree growers have more potential to practice regulated deficit irrigation than do field and row crop growers due to the greater separation between vegetative and reproductive growth stages in trees compared with field and row crops.

Stages of Growth

Stages of growth vary between tree species and between varieties within a species. In general, the stages of growth are Stage 1 (February to June)—early season (bud break through fruit set); Stage 2 (May to July)—fruit growth and development; and Stage 3 (August to October)—postharvest.

Plums

One experiment in the US showed that cutting off irrigations from 12 to 45 days before harvest had no effect on the yield of plum trees. Another experiment showed that that cutting off the water during any one stage of growth had no effect of crop yield as long as adequate irrigations occurred in the other stages of growth. However, trees with lower dry fruit yield in one year increased yields the following year, and vice versa.

Peach

Regulated deficit irrigation was imposed on late season and early season peaches. The stress periods were from the end of April to the end of June and postharvest for the late-season variety, and postharvest only for the early season variety. Soil type was sandy loam. The trees were irrigated with microsprinklers.

Except for one year, the late-season variety showed little difference in fruit yield due to deficit irrigation. However, smaller fruit size occurred for deficit-irrigated trees, with fewer "oversized" fruit and more medium-and small-sized fruit. For fresh-market production, this shift resulted in a significant revenue reduction.

Increased production of fruit doubles and deep-sutured fruit occurred for early-season fruit irrigated at about 25 percent of potential evapotranspiration after harvest. Water savings of about 60 percent of that normally applied were achieved. Production of fruit doubles and deep-sutured fruit was reduced by a heavy irrigation in mid-August, resulting in a 30 percent water savings. The conclusion was that regulated deficit irrigation coupled with a late-summer heavy irrigation appears to be a viable technique for water savings.

Pistachios

Regulated deficit irrigation did not affect yield for irrigation at 50 percent of the potential crop water use during stage 2 growth (May 16 to June 30) and at 25 percent of the potential crop water use during postharvest (after September 16). Stress during stage 3 (early July through harvest) should be avoided. Recommended crop coefficients for regulated deficit irrigation are shown in Table 1.

Olive

Regulated deficit irrigation of olives from June 1 through September 15 showed no effect on crop yield. One approach applied 50 percent of the potential crop water use between June 1 and August 15 while another approach applied 50 percent of the potential crop water use between May 16 and June 15 and between August 16 and September 15, and 25 percent of the potential crop water use between June 16 and August 15.

Table 1. Crop coefficients for pistachios under regulated deficit irrigation.

Growth Stage	Approximate	Period	Crop Coefficient	RDI[1] Level
	Bloom	Apr 1-15	0.07	100
Stage 1	Leafout	Apr 16-30	0.43	100
	Shell expansion	May 1-15	0.68	100
	Shell hardening	May 16-31	0.93	50
Stage 2	Shell hardening	Jun 1-15	1.09	50
	Shell hardening	Jun 16-30	1.17	50
	Nut filling	July 1-15	1.19	100
	Nut filling	July 16-31	1.19	100
Stage 3	Nut fill/shell splitting	Aug 1-15	1.19	100
	Shell splitting	Aug 16-31	1.12	100
	Hull slip	Sept 1-15	0.99	100
	Harvest	Sept 16-30	0.87	25
	Postharvest	Oct 1-15	0.67	25
Postharvest	Postharvest	Oct 16-31	0.50	25
	Postharvest	Nov 1-15	0.35	25

[1] Level of irrigation for various stages of growth.

IRRIGATION WATER COMPOSITION AND SALINIZATION

All irrigation water contains dissolved mineral salts, but the concentration and types n of dissolved salts varies according to the source of the water and from one part of the growing season to another. Since salts can impair plant growth, farmers need to know the salinity of irrigation water at various times of the year.

Dissolved salts in irrigation water form particles. The major particles are sodium, calcium and magnesium, which are all positively charged, and chloride, sulfate, and bicarbonate, which are all negatively charged.

The salinity of the irrigation water is most often expressed by its electrical conductivity, but may also be expressed in a number of other ways, depending on the method and purpose of the measurements. The concentrations of the constituents listed above are usually expressed in milliequivalents per liter (meq/l) or milligrams per liter (mg/l). The latter is numerically equivalent to parts per million (ppm). Total dissolved solids (TDS) is usually expressed in mg/l or ppm.

The presence of salts in irrigation water primarily results from the chemical weathering of earth minerals (from rocks and soils). Much of the salt in geological formations has dissolved over millions of years and has been transported naturally by water. This salt terminates in the ocean or in closed basins where it has concentrated through evaporation. The remaining fresh water percolates into the ground, dissolving salts from the earth minerals it contacts.

Salts that accumulate in crop root zones, therefore, may come either from the irrigation water or from the soil and other conditions at the irrigated site. Salts in irrigation water can come not just from primary sources (that is, chemical weathering), but also from saline drainage water and seawater intrusion. Similarly, salts at the irrigated site may come not just from dissolution of soil minerals, but also from saline water tables, fertilizers, and soil amendments (such as gypsum and lime).

A soil is *salinized* when the salt concentration in the root zone reaches a level too high for optimum plant growth and yield. Irrigation must therefore be managed to maintain an optimum salt balance in the crop root zone. A favorable balance occurs when the quantity of salts leaving the root zone is at least equal to that entering the root zone. Without a favorable salt balance, the soil will become salinized.

HOW PLANTS RESPOND TO SALTS

Although all agricultural soils and irrigation water contain salt, the amount and type of salts present depends on the makeup of both the soil and the irrigation water. A soil is not considered saline unless the salt concentration in the root zone is high enough to prevent optimum growth and yield.

Salts dissolved in the soil water can reduce crop growth and yield in two ways: by salt influences and by specific-ion toxicities. Salt effects are the processes by which salts most commonly reduce crop growth and yield.

Plants vary widely in their response to soil salinity. Some plants actually grow better under high levels of soil salinity. These plants can adjust to the increased salinity of the soil water largely by accumulating salts absorbed from the soil water. Salts accumulate in the root cells in response to the increased salinity of the soil water, thus maintaining water flow from the soil to the roots.

Most crop plants can be affected by even moderate soil salinity levels — although salt tolerance within this group varies widely. These plants adjust to increased soil salinity, but by doing so, energy is used that normally would be used for plant growth. Thus, crop growth and yield are reduced more so that would occur for salt tolerant crops.

Salinity can also affect crop growth through the effect of chloride, boron, and sodium ions on plants — called *specific-ion toxicities* — which occurs when these constituents in the soil water are absorbed by the roots and accumulate in the plant's stems or leaves. Often high concentrations of sodium and chloride occur with high salinity levels. High sodium and chloride concentrations can be toxic to woody plants such as vines, avocado, citrus, and stone fruits. Boron is toxic to many crops at relatively low concentrations in the soil. Often the result of specific-ion toxicity is leaf burn, which occurs predominately on the tips and margins of the oldest leaves. Boron injury has also been observed in deciduous fruit trees as "twig die back".

Plant sensitivity to salinity also depends on the plant growth stage— germination, vegetative growth, or reproductive growth. Many crops — cotton, tomato, corn, wheat, and sugar beets, for example — may be relatively sensitive to salt during early vegetative growth, but may increase in salt tolerance during the later stages. Other plants may respond in an opposite manner. Research on this matter is limited, but if salinity during emergence and early vegetative growth is below levels that would reduce growth or yield, the crop will usually tolerate more salt at later growth stages than crop salt tolerance guidelines indicate.

SODIUM AND CHLORIDE TOXICITY IN CROPS

Salinity can stunt plant growth by forcing the plant to work harder to extract water from the soil. Sodium and chloride — usually the major constituents in salt-affected soils — can cause additional damage to plants if they accumulate in the leaves to toxic concentrations — either by being absorbed through the roots and moving into the leaves or by being absorbed by the leaves directly from sprinkler irrigation.

Damage from sodium and chloride toxicity usually occurs only in tree and vine crops except where soil salinity is extremely high or when saline water is used for sprinkler irrigation. Under these conditions, non-woody annuals may also show leaf injury.

In most crops, most of the sodium absorbed by the plant remains in the roots and stems, away from leaves, but sodium, which is not an essential micronutrient, can injure woody plants (vines, citrus, avocado, stone fruits) if it accumulates in the leaves to toxic levels. Direct toxic effects — including leaf burn, scorch, and dead tissue along the outer edge of leaves — may take weeks, months, and in some cases, years, to appear, although once concentrations reach toxic levels, damage may appear suddenly in response to hot, dry weather conditions. Symptoms are first evident in older leaves, starting at the tips and outer edge and then moving inward toward the midrib as injury progresses. Injury in avocado, citrus, and stone fruits can occur with soil-water concentrations as low as 5 meq/liter. Damage can also result when sodium is absorbed by the leaves during sprinkler irrigation.

Sodium can also affect crop growth indirectly by causing nutritional imbalances and by degrading the physical condition of the soil. High sodium levels can cause calcium, potassium, and magnesium deficiencies — and high sodium levels relative to calcium concentrations can severely reduce the rate at which water infiltrates the soil, which can affect the plant because of poor aeration.

Chloride, an essential micronutrient, is not toxic to most nonwoody plants unless excessive concentrations accumulate in leaves. While many woody plants are susceptible to chloride toxicity, tolerance varies among varieties and rootstocks. Many chloride-sensitive plants are injured when chloride concentrations exceed 5 to 10 meq/liter in the saturation extract, while nonsensitive plants can tolerate concentrations up to 30 meq/liter.

Chloride moves readily with the soil water, is taken up by the plant roots, translocates to the shoot, and accumulates in the leaves. Chloride injury usually begins with a chlorosis (yellowing) in the leaf tip and margins and progresses to leaf burn or drying of the tissue as injury becomes more acute. Chloride injury can also result from direct leaf absorption during overhead sprinkler irrigation.

CROP SALT TOLERANCE

The salt tolerance of a crop is the crop's ability to endure the effects of excess salt in the root zone. In reality, the salt tolerance of a plant is not an exact value, but depends upon many factors, such as salt type, climate, soil conditions and plant age.

Agriculturalists define salt tolerance more specifically as the extent to which the relative growth or yield of a crop is decreased when the crop is grown in a saline soil as compared to its growth or yield in a non-saline soil. Salt tolerance is best described by plotting relative crop yield at varying soil salinity levels. Most crops can tolerate soil salinity up to a given threshold — that is, the maximum salinity level at which yield is not reduced. Beyond this threshold value, yield declines in a more or less linear fashion as soil salinity increases.

Table1 lists threshold soil salinity levels and relative ratings for row and field crops grown in the Highlands area. Table 2 shows the same information for tree and vine crops grown in the Highlands area.

Table 1. Threshold soil salinity levels and ratings for row and field crops.

Crop	Threshold Value (dS/m)	Rating
Barley	8.0	S
Broad Bean	1.6	MS
Carrot	1.0	S
Corn	1.7	MS
Cucumber	2.5	MS
Eggplant	1.1	MS
Garlic	3.0	MS
Green Bean	1.0	S
Lettuce	1.3	MS
Melon	----	MS
Okra	----	S
Onion	1.2	S
Pea	----	S
Pepper	1.5	MS
Radish	1.2	MS
Spinach	2.0	MS
Squash (zucchini)	4.7	MT
Tomato	2.5	MS
Wheat	6.0	T

S: Sensitive.
MS: Moderately Sensitive.
MT: Moderately Tolerant.
T: Tolerant.

Table 2. Threshold soil salinity levels and ratings for row and field crops.

Crop	Threshold Value (dS/m)	Rating
Apple	----	S
Citrus	1.7	S
Date	4.0	T
Grape	1.5	MS
Olive	----	MT
Peach	1.7	S
Plum	1.5	S

S: Sensitive.
MS: Moderately Sensitive.
MT: Moderately Tolerant.

SALT DISTRIBUTION UNDER DRIP IRRIGATION

Salt movement is governed by water movement. Under drip irrigation, water moves in a more or less radial pattern around the emitter. Soil salinity eventually reflects this pattern of water movement.

Figure 1 shows salinity patterns for two different leaching fractions under surface drip irrigation. The following can be concluded from these patterns:

• Salinity is lowest directly beneath the emitter. This low salinity zone is largest with the high leaching fraction and smallest with the low leaching fraction.

• Salinity gradually increases as the distance from the emitter increases. The increase is smallest in the vertical direction and largest in the horizontal direction. With the low leaching fraction, levels of increased salinity occur closer to the emitter.

• Salinity is highest midway between emitters. This zone is smallest with the high leaching fraction and largest with the low leaching fraction. At the midway point, salinity decreases as the depth increases.

These salt patterns reflect water movement during and between irrigations. During irrigations, salt leaching takes place in the vicinity of the emitter. The amount of leaching depends on the leaching fraction, or the amount of applied water in excess of the crop water use. The higher the leaching fraction, the larger the low-salt zone. The infiltrating water carries these leached salts away from the emitter. As the horizontal distance from the emitter increases, soil salinity increases because the amount of leaching decreases. Salt accumulation is highest midway between emitters because little or no leaching occurs in those areas.

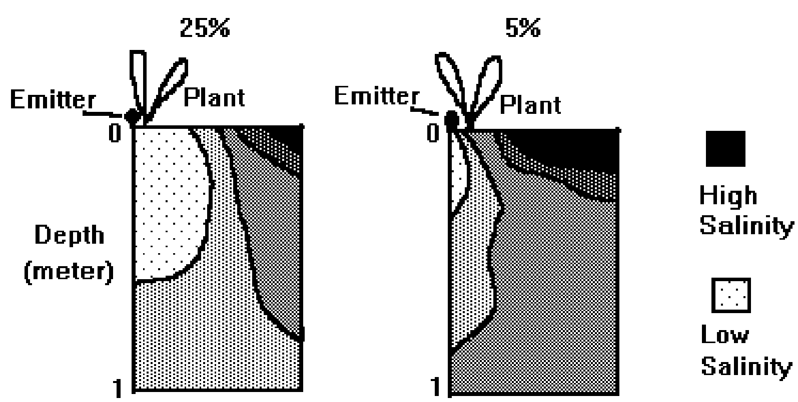

Figure 1. Salt distribution under drip irrigation for two different amounts of leaching.

APPLYING WATER EFFICIENTLY WITH DRIP IRRIGATION

One factor affecting efficiency irrigation with drip irrigation is the uniformity or evenness at which irrigation water is applied over a field. The more evenly water is applied over a field, the potentially more efficient the irrigation. If every part of the field were to receive the same amount of water, uniformity would be 100 percent, but as a practical matter, no irrigation system can achieve 100 percent uniformity—some parts of the field always receive more water than other parts. When the uniformity of a system is particularly poor, some parts of the field may have to be severely over-irrigated so that the areas receiving less water in a given period will be adequately irrigated. This over-irrigating can cause excessive deep percolation.

In drip irrigation, uniformity depends on the extent to which emitter flowrates are the same throughout the field. The more variation in emitter flowrates, the less uniform the irrigation. Differences in emitter flowrates are caused by:

• emitter clogging—the physical blocking of emitter flow passages as a result of materials suspended in the water, precipitated chemicals, slimes and bacteria growing within the system. Clogging can be prevented or corrected by proper filtration and chemical treatment to dissolve precipitates in the emitters.

• pressure variation within the irrigation system caused primarily by friction in mainlines, submains, and laterals and by elevation differences in the system. Proper system design will minimize pressure variation.

• the relative sensitivity of the emitters to pressure differences;

• variations in the size or shape of emitter flow passages and orifices caused by eccentricities in the manufacturing process—called the *coefficient of manufacturing variation*, or *CV*.

• the system design, in particular, the length of the lateral lines, diameter of laterals, and characteristics of the emitters used.

The uniformity of a drip system can be defined by calculating the *emission uniformity*, (sometimes referred to as the *distribution uniformity*)—specifically, the minimum emitter flowrate—usually the average of the lowest one-fourth of measured emitter flowrates—divided by the average emitter flowrate. These values are obtained by measuring emitter flowrates throughout the irrigation system.

A second factor affecting efficient irrigation is management of the system. Efficient irrigation means that the amount of water use by the crop between irrigations should be known, and that amount of water should be applied by the drip system. No matter how uniform water is applied over a field, low efficiency will occur if too much water is applied.

DESIGNING A DRIP IRRIGATION SYSTEM FOR EFFICIENT IRRIGATION

Components of a Drip Irrigation System

Components of a typical drip irrigation system generally include:

a pump
a flowmeter
mainlines, submains and manifolds
drip tubing with emitters for lateral lines
pressure regulators
valves
a filter
injection equipment

The pump and motor (or engine) chosen should be one that delivers the right pressure and flowrate as efficiently as possible. It is important to insure that the right pressure is delivered to the furthermost part of the irrigation system to maintain good uniformity throughout the field. Many drip systems in the Highlands area do not have sufficient pressure throughout the field.

Flowmeters measure the volume of water moving through the system, making it possible to calculate how much water is being applied and therefore how often and how long the irrigation system should operate to obtain maximum yield.

Main and submain pipes deliver water to the lateral lines and emitters. These should be properly sized to prevent excessive pressure losses in the irrigation system. Proper sizing of pipelines involves pipe diameter, pipeline length, flow rate, and elevations differences. A qualified drip irrigation system designer will take these factors into account in recommending pipe sizes

Valves and regulators control water flow and pressure in the drip system. Check valves are installed at the pump discharge to prevent water from flowing backward into the well. Pressure-regulating valves help maintain a constant downstream pressure. Pressure-relief valves protect against pressure surges that might damage pipelines. Few, if any drip systems in the Highlands area have any type of pressure regulation.

Layout of a Drip Irrigation System

Figure 1 shows a typical design of a drip irrigation system. The field is split into blocks, each block containing lateral lines connected to a manifold. The manifold, in turn, is connected to a submain. Some type of pressure control is installed at the manifold inlet to ensure uniform pressure throughout the field. Submains are then connected to the mainline. A flushing manifold connected to the end of the laterals may be installed at the end of the block.

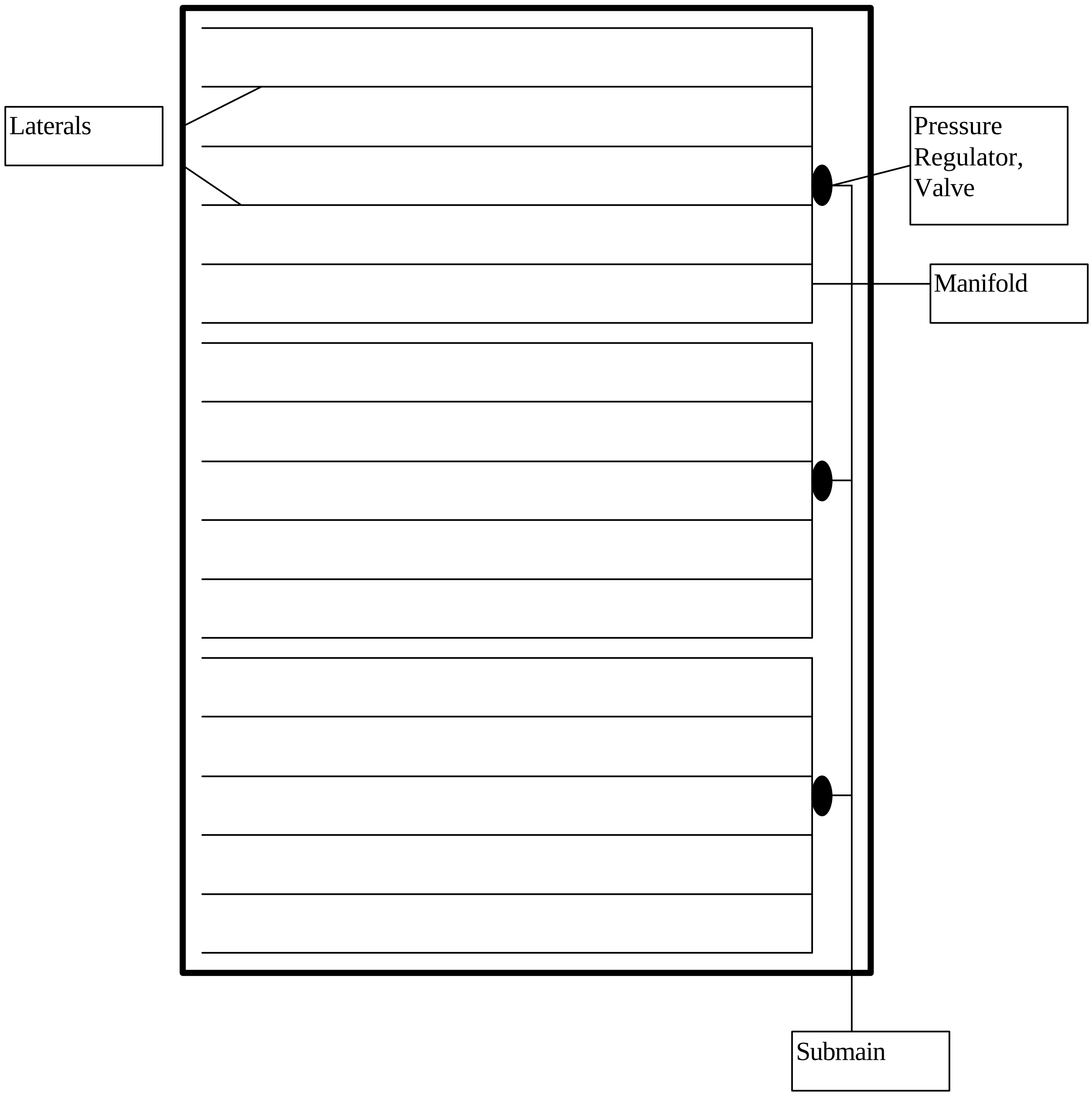

Figure 1. Layout of a drip irrigation system designed for good uniformity.

Appendix C
Proposed Training Course for Irrigation Advisors

Appendix C – Proposed Training Course for Irrigation Advisors

1. Overview of irrigation problems in Jordan – surface water, groundwater, aquifer recharge, water demand by agriculture, urban, and environmental sectors, future water demand and supplies.

2. Evapotranspiration
    a. What is evapotranspiration?
    b. What affects evapotranspiration?
        1. Plant
        2. Climate
        3. Soil
    c. Relationship between yield and evapotranspiration for different crops
    d. Relationship between yield and applied water
    e. What causes water flow to occur in plants?
    f. Water uptake by roots – root distributions as affected by irrigation amounts and timing, root distributions as affected by irrigation method.
    g. Critical growth stages

3. Measuring evapotranspiration
    a. What is a millimeter of water?
    b. Methods – climatic data, lysimeters, evaporation pans, soil moisture measurements.
    c. Reference crop evapotranspiration
    d. Crop coefficients of tree crops and row crops
    e. Calculating crop evapotranspiration

4. Soil moisture
    a. What is soil?
    b. Describe how soil moisture is held in soil
    c. Definitions of soil moisture content and soil moisture tension. Show relationships between soil moisture content and tension for different soil types.
    d. Define field capacity, 15 bar soil or permanent wilting point, and available soil moisture content
    e. Define allowable soil moisture depletion
    f. Describe methods for measuring soil moisture
        1. Soil probe and “feel” method
        2. Tensiometers
        3. Electrical resistance blocks (Watermark blocks and gypsum blocks)
        4. Neutron moisture meter
        5. Dielectric soil moisture sensors
        6. Soil sampling – gravimetric moisture content, volumetric moisture content, bulk density
    g. Recommendations for irrigation based on soil moisture depletions

5. Water quality concerns
    a. Soluble salts affecting the salinity of water
    b. Crop tolerance of salinity
    c. Toxic effects – sodium, chloride, boron
    d. Salinity control
        1. Define leaching requirement and leaching fraction
        2. Define maintenance leaching and reclamation leaching
        3. Calculate leaching fraction

6. Irrigation efficiency and uniformity
    a. Define irrigation efficiency
        a) Different methods of calculating irrigation efficiency
        b) Beneficial uses of irrigation water
            1. Crop evapotranspiration
            2. Leaching
            3. Climate control – frost protection, cooling
            4. Maintenance of drip irrigation systems
        c) Losses affecting irrigation efficiency
            1. Percolation below root zone
            2. Surface runoff
            3. Evaporation
    b. Define uniformity of applied or infiltrated water
        a) Measuring uniformity
        b) Indices for describing uniformity
            1. Distribution and emissions uniformity
            2. Discharge ratio
            3. Other
        c) Relationship between uniformity and irrigation efficiency

7. Measuring water
    a. Types of flow meters
    b. Installation and operation conditions
    c. Calculating depth of applied water

8. Developing an irrigation schedule
    a. Surface/sprinkler irrigation
        1. Calculating crop evapotranspiration
        2. Calculating available soil moisture
        3. Determining the allowable depletion
        4. Calculating the desired interval between irrigations
    b. Drip irrigation/minibasins
        1. Calculating crop evapotranspiration
        2. Selecting an irrigation interval
        3. Measuring emitter discharge rates
        4. Calculating the irrigation set time

9. Principles of hydraulics
    a. Factors causing water flow in pipelines
    b. Friction losses
        a) Factors affecting friction losses
            1. Diameter
            2. Pipe material
            3. Length
            4. Multiple outlets
            5. Age of pipe
        b) Calculating friction losses

    c. Elevation differences

10. Drip irrigation
    a. Types of drip systems
    b. Types of emitters/microsprinklers
    c. Design considerations of drip systems
        a) Uniformity standards
        b) Design considerations
            1. System layout
            2. Lateral lengths
            3. Submain/manifold design considerations
        c) Pressure control
            1. Factors causing pressure losses
            2. Controlling pressure losses
                a. System design
                b. Pressure regulation – types of regulators
    d. Water quality and clogging
        a) Factors causing clogging
        b) Estimating the potential of a water to cause clogging
    e. Filters
        a) Types of filters
        b) Selecting a filter
        c) Flow rate considerations for proper filter operation
        d) Flushing filters
        e) Water quality concerns
    f. Chemigation to control clogging
        a) Acid injection
        b) Chlorine injection
    g. Injection equipment
        a) Batch tanks
        b) Venturi
        c) Positive displacement pumps – water driven, motor/engine driven
        d) Location of injection points
        e) Safety/environmental concerns – backflow prevention

- h. Fertigation
    - a) Characteristics of fertilizers for drip irrigation
    - b) Fertilizer requirements
    - c) Calculating injection times
    - d) Uniformity of fertilizers injected into drip systems
- i. Water and salt patterns under drip irrigation
- j. Special case of minibasins

11. Irrigation pumps
    - a. Description of irrigation pumps
        - a) Deep-well turbines
        - b) Centrifugal or booster pumps
        - c) Submersible pumps
    - b. How does a pump operate?
    - c. Performance characteristics of pumps
    - d. Pump selection
    - e. Maintaining your pump
    - f. Pumping problems
        - a) Worn pump
        - b) Declining water levels
        - c) Insufficient suction lift
    - g. Electric motors
    - h. Engines

Appendix D
Possible Equipment Requirements for an Irrigation Advisory Service Program

Appendix D – Possible Equipment Requirements for an Irrigation Advisory Service Program

1. Vehicles for field work
2. Soil moisture sensors
    a. Tensiometers
    b. Watermark blocks/meter
    c. Soil probes
3. Soil augers
4. Soil moisture cans
5. Oven for drying soil samples
6. Scale for weighing soil samples
7. Pressure chamber for measuring leaf water potential of tree crops
8. Flow meters
9. Graduated cylinders
10. Measuring tape
11. Meter for measuring electrical conductivity of water
12. Tools and tool box
13. Computer and appropriate software.

SUMMARY, AND IMPLICATIONS, OF THE REPORT OF THE IRRIGATION ADVISORY SPECIALIST, DR. BLAINE HANSON, AUGUST, 2000

The limited water supply in the Amman-Zarqa Basin Highlands area means that farmers must irrigate as efficiently as possible in order to conserve groundwater resources and improve profitability. Efficient irrigation involves good irrigation system design, maintenance, and management.

Dr. Hanson studied the feasibility of establishing an irrigation advisory service (IAS) and wrote a technical report on his findings (the executive summary of his report is attached).

Irrigation efficiency was evaluated on a sample of farms, with the following results:

- Substantial irrigation inefficiencies were measured, in terms of a lack of uniformity of applied irrigation water, and in terms of significant over-irrigation
- Farmers generally have little knowledge about the performance characteristics of their irrigation systems
- Farmers generally are not aware of the importance of irrigation efficiency in improving profitability and conserving groundwater resources.

From these results, Dr. Hanson concluded that Highlands farmers could significantly improve irrigation water efficiency through obtaining a better understanding of the inefficiencies of their current systems, and through adopting improved irrigation practices. It is difficult from this brief analysis to estimate the potential water savings which are possible in practice, but a value of 15-20% of existing water use would be consistent with the results of the sample; this would imply a potential annual savings in Amman-Zarqa Basin groundwater resources of at least 5-15MCM.

In order to make the potential improvements in irrigation efficiency, a program of farmer education and technical assistance will be needed. Dr. Hanson recommended that a pilot extension scheme be initiated in a limited area, to test the feasibility of establishing an irrigation advisory service.

The objective of the IAS pilot program would be to help a small number of farmers in the Highlands area improve their water management practices through farmer education and demonstrations, and based on these results, evaluate the potential for expanding the program to reach a relatively large number of farmers.

Dr. Hanson suggested the following procedure for developing a pilot program:

- Identify farmers who would be willing to participate in a pilot program (completed).
- Visit the farmers and explain the objectives and activities of the program (completed).
- Develop contacts with private sector firms that might be interested in being involved in the IAS pilot program and in continuing the IAS program after the pilot project is completed (in progress).
- Determine and purchase the equipment and support needed to conduct both educational and applied research activities.
- Start the program by contacting the interested farmers and start installing instruments and conducting experiments.
- Conduct educational activities to disseminate the results of the program to all interested farmers.
- Expand the program as needed.